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THE PHILIPPINE

JOURNAL OF SCIENCE

A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. X SEPTEMBER, 1915 No. 5

THE PERSISTENCE OF PHILIPPINE COAL BEDS[1]

By WALLACE E. PRATT

(From the Division of Mines, Bureau of Science, Manila, P. I.)

THREE TEXT FIGURES

Coal was discovered in Cebu as early as the year 1827, and within the next thirty years practically all the more important Philippine coal fields had become known. The Spanish Government made repeated attempts to develop an industry in coal mining both by fostering private enterprises and by undertaking to exploit some of the deposits in the name of the state itself. Similarly the American Government has sought to establish coal mining. Coal is one of two mineral products which may be exported from the Philippines free of duty; a tax must be paid on imported coals; coal-mining companies have received special favors at the hands of the Government even to the extent of financial assistance; and the United States Army opened a coal mine on its own account. Yet in spite of the long lapse of time since coal was discovered in the Philippines, and in spite of the many attempts at coal mining, no coal is produced in the Philippines to-day.

There are several good reasons for this state of affairs. Perhaps the greatest difficulty is that the coal is not of superior quality. Black lignites and subbituminous coals make up the greater part of the Philippine coal resources. Some of the coal fields are inaccessible. The roof and floor of the beds are soft and require close timbering. The coal is liable to spontaneous combustion, both in the mine and in storage. But the obstacle which has stood most directly in the way of developing coal mines is the discontinuity of the beds.

[1] Received for publication June 25, 1915.

Practically every attempt at prospecting has had to contend with the difficulty that the tunnels ran out of coal sooner or later under circumstances which made it difficult to decide whether the coal bed had been faulted or had failed by pinching out. It will readily be understood that a nearly vertical fault, more or less parallel to the strike of an inclined coal bed, might so displace the coal on either side of the fault plane that the bed would appear to pinch out gradually.

The true nature of the discontinuities in Philippine coal beds cannot be determined by geologic study alone. Outcrops are notoriously unreliable where the surface relations are so obscured by slides, by talus, and by the growth and decay of heavy vegetation, as they are in the Philippines. In certain individual cases it is clear that beds have been faulted, and less commonly unmistakable evidence that the original bed was of restricted lateral dimensions is to be found in gradually decreasing thicknesses along outcrops. But to decide which is the common cause of nonpersistence and usually to decide which factor is responsible in a particular case, underground exploration is necessary.

The exploration which has been carried out in the past throws some light on this problem, and it seems desirable to bring the results together for comparison and study. The work of exploration having been restricted to a few localities, the study cannot be made exhaustive, but an attempt to interpret the data which are available should be useful as a guide to future exploration.

The Spaniards performed and recorded the results of a great deal of exploration in coal beds, and their works should be reviewed briefly in this connection.

About the year 1874 an association called "La Paz" was organized to exploit certain deposits of coal which outcrop in the vicinity of San Esteban, a barrio of Bacon, Sorsogon. The outcrops appear to represent several beds, but the principal work was confined to a single bed, which, according to José Centeno, an engineer in the Spanish mining inspectorate, varied in width from 4 to 8 meters. All of the beds are nearly vertical and strike about north 20° west. The coal lies near the base of the Tertiary sedimentaries, and at the western edge of the sedimentary area—below the coal—there are outcrops of holocrystalline rocks which probably are part of the base upon which the beds were laid down.

The workings executed by the La Paz association, according to Centeno, included 6 shafts varying in depth from 22 to 34 meters and 5 galleries and crosscuts aggregating 66 meters in

length. Ramon Marty, an engineer employed by the company, states that 130 meters of gallery were driven at a level 11 meters below the surface and 188 meters of gallery at a level of 24 meters below the surface, beside the 6 shafts mentioned by Centeno. No faults were encountered, but the width of the coal varied from 4 to 8 meters, and there were zones near the surface in which the coal was broken and contaminated with fragments from the walls. Marty observed that the deepest workings were in good, solid coal and concluded that the broken condition of the coal was superficial only.

The coal was considered to be of excellent quality, 200 tons of it having been used for steaming tests by the Spanish navy. It was admitted, however, that the fuel tended to disintegrate, or slack, upon exposure. Both Centeno and Marty thought that mining could be carried on successfully and expressed no doubt as to the adequacy of the tonnage probably available. Nevertheless, very little was accomplished subsequent to the date of the reports quoted above. The company, La Paz, failed, apparently because of a lack of capital, and the mines were abandoned.

I visited the old mines in 1910, and while nothing remained of the former workings I found several outcrops, upon one of which a short tunnel had recently been driven. This bed is vertical and strikes north 20° west; its full width was not revealed but must exceed 2 meters. The tunnel was about 10 meters long and entirely in coal, neither wall being exposed. The coal appeared to be much contaminated with clay along fractures and in inclosed blocks or horses.

It may be concluded that the coal at San Esteban (designated variously as the Gatbo coal, the Sugud coal, and the Bacon coal) shows evidence of faulting in the broken condition of parts of the beds. The variation in width, also, may be due to the movements which caused the faults or it may be due to irregularities in deposition. The testimony of the Spanish engineers that conditions improved with depth suggests that faulting, not irregular deposition, is really the cause of the nonuniformity encountered, and the exploration so far as it goes indicates persistent coal beds.

Spanish engineers, also, directed important explorations of coal beds at Danao, Compostela, Guilaguila, and Uling in the Province of Cebu. The workings at Danao (barrio of Camansi) aggregated several thousand lineal meters and perhaps 10,000 square meters of rooms. Three or four different beds appear to have been explored, the thickness of which is from 0.5 to 1.5

meters on an average. A number of faults were encountered, and with few exceptions the coal was not recovered beyond the faults. On the other hand, the beds are fairly constant in thickness, and no evidence of irregularities due to the character of the original deposition is recorded.

At Compostela, also, numerous tunnels were driven and rooms were opened, the work done being about equal in the aggregate to that at Camansi, Danao. Two beds were exploited, both of which were regular and in the neighborhood of 1 meter in thickness. Two faults were encountered, one of which was of minor importance and caused little trouble, while the other cut off the coal so effectually that it was not again located. The sketches in fig. 1, taken from annual reports of Enrique Abella y Casariego, chief inspector of mines at that time, illustrate the effect of the smaller fault.

The coal is of the same character at Camansi and Compostela and ranks as a superior subbituminous coal. It was used satisfactorily as a steaming coal. The attempts at mining encountered difficulties on account of faults, but did not reveal any evidence of the pinching out of the beds, even though they were not of great thickness.

Spanish mining at Guilaguila, on the other hand, demonstrated that a bed of coal from 1 to 2 meters in thickness changed its character within a short distance to a series of thin layers intercalated with rock. However, the deposits at Guilaguila are known to overlie very closely the basement upon which the coal-bearing rocks were deposited, and it is not surprising that the conditions for deposition were rapidly changing and inconstant. The work at Guilaguila was carried on by the Spanish Government about the year 1853.

At Uling, Cebu, the Spaniards executed their most valuable work of exploration. There are several (probably five) beds of coal outcropping on the eastern slope of Mount Uling and dipping at an angle of from 30° to 40° west-northwest into the mountain. One of these beds, the outcrop of which is about 100 meters vertically above the level of the base of the mountain, is 5 meters thick at the surface. Doña Margarita Roxas, a most energetic woman, undertook the exploitation of this coal bed about 1860. She built 15 kilometers of mountain road extending from Tinaan on the coast to Alpaco, where she was carrying on other exploratory work, and thence north to Mount Uling. Having discovered by openings on the outcrop that the large bed was faulted near the surface, but that the faulted coal was intact and continuous for some distance beyond the fault, she determined

upon the excavation of a transverse drainage tunnel from the lowest practicable point to the extension of the large vein at depth.

This tunnel was driven through shale and sandstone a total distance of 647 meters and actually reached the large bed. But shortly after its completion the lady whose enterprise was re-

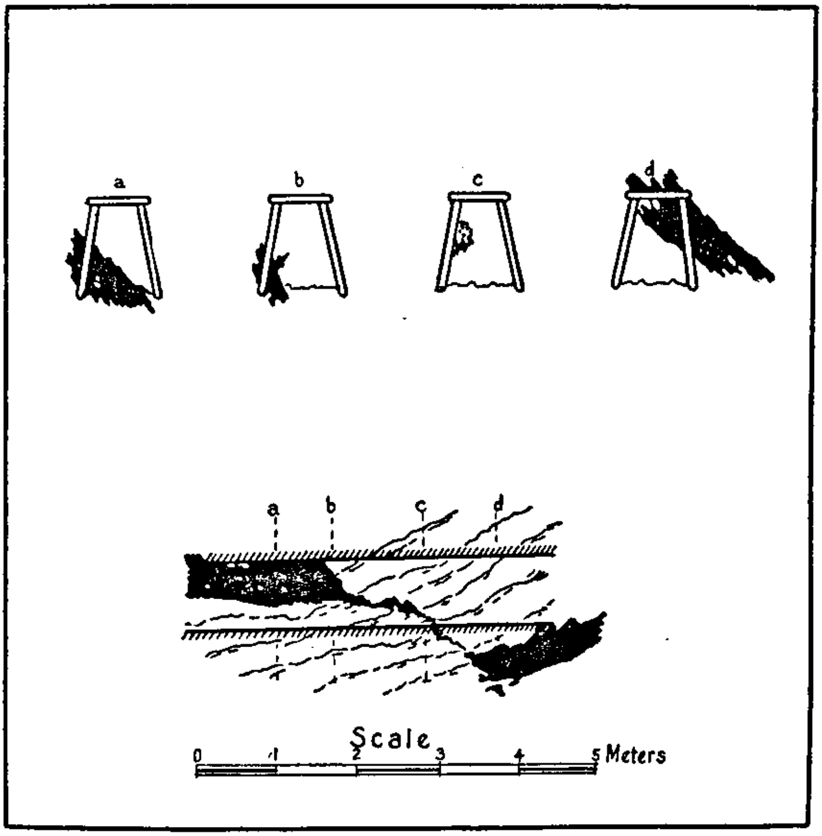

FIG. 1. Plan of Esperanza gallery at Compostela coal mine, Cebu, showing its passage through a fault, with sections across gallery at *a*, *b*, *c*, and *d*.

sponsible for the successful termination of the undertaking, which in that time must have been very difficult, died, and her work was allowed to fall to ruin. The tunnel encountered three other smaller beds of coal before it finally reached the large bed, and these results were carefully recorded by the engineers of the Spanish inspectorate. Abella estimated that a minimum quantity of 600,000 tons of coal was developed with reasonable certainty by this work, and the persistence of the large bed was

proved for a distance of approximately 200 meters down the dip and 150 meters along the strike.

Nevertheless the fact that the enterprise was abandoned just when its success seemed assured and was never resumed made the records appear questionable to American interests which came into control of the Uling field recently, and exploration was renewed to verify their correctness.

The recent exploration at Uling, which was conducted under my supervision, began with a slope entry on the 5-meter outcrop. This slope followed the floor of the bed for a distance of about 20 meters from the intersection of the bed with the surface, where a fault was encountered. This fault is parallel to the strike of the coal, but dips in the opposite direction—that is to say, the coal dips about 35° westward, while the fault dips about 30° eastward. The coal is truncated sharply along the fault,

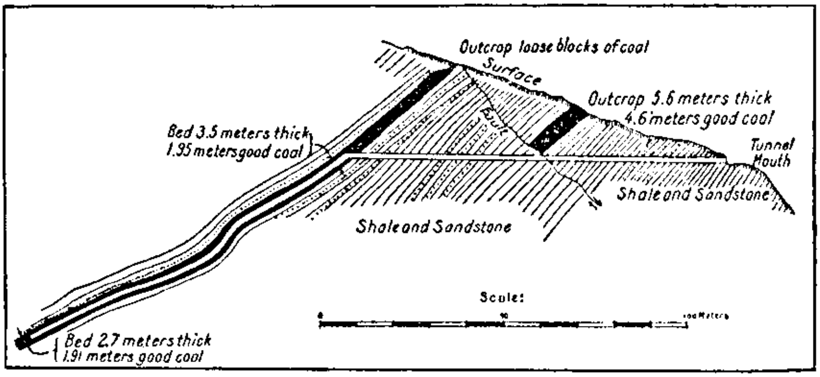

FIG. 2. Sketch, showing in section exploration work on a 5-meter coal bed at Uling, Cebu.

and there is little evidence of drag or movement along the fault plane. It was fairly clear, however, assuming that a normal fault had caused the displacement, that the continuation of the coal beyond the fault would be encountered by following the fault upward; in other words, the outcrop coal dropped along the fault.

It was decided to do no more work on the slope because of the inconvenience entailed in changing the grade from the fault plane forward, but instead to drive a new tunnel from a point about 50 meters farther north along the outcrop. This tunnel was driven so as to drain itself, and its portal was located about 10 meters lower than the outcrop. The fault plane was intersected at 48 meters from the portal, and at 121 meters the tunnel reached the coal bed beyond the fault. The last 20 meters of the tunnel were in sandstone and shale which showed no

evidence of fracture or displacement, but nearer the mouth, and especially in the vicinity of the main fault, the rocks were disturbed, slickensided, and broken. It is estimated that the coal had been displaced by this fault through a distance of about 40 meters measured along the fault plane.

Once having reached the coal beyond the fault, the tunnel was advanced as a stope (driven in parallel) on the full dip of the bed and carried 98.4 meters farther when old workings were encountered (fig. 2). It was concluded that the old workings probably had been driven up the dip from the face of the long Spanish transversal tunnel which, therefore, must have reached the bed as the records show. Unfortunately it became necessary to suspend the exploration at this point, although the results of the work so far completed had been fairly satisfactory.

At the outcrop of the faulted block the bed has a thickness of 5.60 meters between roof and floor, both of which are sandy shale and sandstone. About 4.75 meters of this is coal, of which 4.6 meters could be removed economically in mining. There are several parting planes, and there is one narrow parting of carbonaceous shale. About 0.2 meter of carbonaceous shale near the middle of the bed, and 0.6 meter of carbonaceous shale and thin coal at the bottom, would have to be removed as waste. In the driving of the tunnels the middle coal was mined by removing the central layer of carbonaceous shale. This permitted the upper coal as high as the parting to fall, after which the lower coal was taken up down to the lower parting.

The changes which the bed manifested as the work advanced are shown clearly in the accompanying sections (fig. 3). The bed where first encountered beyond the fault is only 3.5 meters thick between floor and roof and contains only 1.95 meters of coal. At the face of the slope, farther down the dip, the bed is still thinner—2.7 meters between floor and roof—but the thickness of the coal is maintained fairly well at 1.91 meters. Thus, while the general tendency is toward a gradually reduced thickness of the bed, the coal itself suffers little diminution below the position of the fault and becomes freer from intermixed shale. The only evidence of disturbance beyond the first fault was a slight roll, undoubtedly the result of a movement too restricted in extension to cause a true fault. However, the conditions of deposition appear to have varied alarmingly within a short distance, and the desired constancy is not proved.

The outcrop of this bed of coal can be traced but a few meters. Yet a kilometer away along the strike exploration was started on two other outcrops adjacent to each other, each of

which revealed 2.75 meters of coal. The work at this point encountered a fault after an advance of 13 meters in the coal. All work was suspended before the ground beyond the fault could be explored, and the true relation of these outcrops to the outcrops farther south remains undetermined.

The Uling coal appears from the foregoing to have undergone faulting which, however, is not serious enough to prevent mining. Evidence of inconstant conditions of deposition is brought out

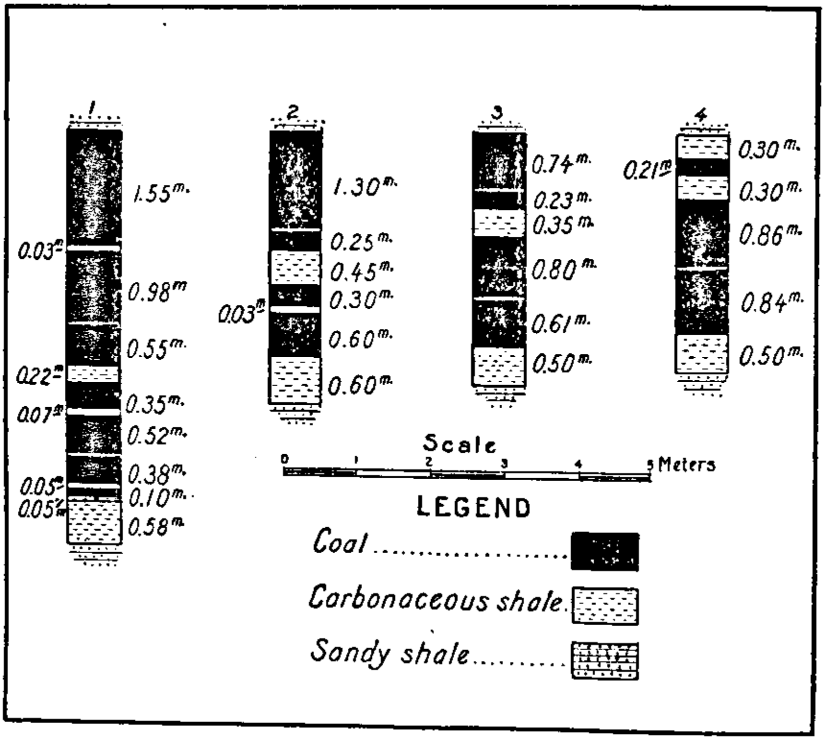

FIG. 3. Sections across 5-meter coal bed at Uling, Cebu. 1, cut section of outcrop of faulted coal; 2, section 10 meters beyond fault; 3, section 58 meters beyond fault; 4, section 84 meters beyond fault.

by the exploration, and the persistence of the coal beds over large areas is questionable. Yet it is not established that the bed has actually pinched out anywhere, and it is entirely possible that further exploration will prove tonnages adequate for commercial exploitation.

The Uling coal is slightly inferior to the Danao and Compostela coal, but is a valuable fuel, especially if it could be used for purposes such as cement burning, where it would be dried and pulverized before combustion.

The most thorough exploration of Philippine coal fields by

Americans was carried out on Batan Island, Albay Province. The western half of this island was reserved by the United States Army for the purposes of coal mining. On the eastern end of the island the East Batan Coal Mining Company developed a mine which yielded from 20,000 to 30,000 metric tons of coal annually for several years. The work of the United States Army demonstrated that faulting was a serious factor in the nonpersistence of the coal beds on the reservation, while the commercial mine at the other end of the island proved the existence of a bed of considerable dimensions with no evidence of faulting and but little indication of inconstant conditions of deposition.

Part of the exploration at the Army mine consisted of diamond-drill work. The results of the drilling are very confusing and difficult of interpretation. A large proportion of the different holes drilled yielded no core because of the softness of the rocks penetrated, and it is probable that the records of strata encountered are faulty on this account. One drill hole, according to its record, penetrated 11 distinct beds of coal, yet it is impossible to correlate these beds with the results obtained in adjacent holes.

The mine workings yielded more definite information. An opening on the Big Tree bed in the upper part of the coal-bearing rocks advanced 14 meters in coal which lay about horizontal and was 2.8 meters thick. For 10 meters the bed was perfectly regular, but within the next 4 meters it decreased in thickness, the floor rising abruptly in steps to about 30 centimeters. The work was abandoned without any attempt to proceed beyond the evidently faulted zone. Other openings of limited extent encountered faults in much the same way.

More important work was performed at New Number 5 mine, in the base of the coal measures. A slope was driven through rock to intersect two beds the presence of which was indicated in adjacent drill holes. The beds appeared to be parallel to each other and to dip at an angle of about 35°. The upper bed was first encountered, and the slope was continued as a drift along the strike of the bed for a distance of 60 meters. Throughout this distance the bed was irregular and showed considerable evidence of squeezing; at the end of the drift the coal was lost along a fault. A horizontal crosscut was driven to the lower bed through the intervening rock strata, a distance of about 10 meters. A drift on the strike of the lower bed from the end of this crosscut, parallel to the drift on the upper bed and at approximately the same level, advanced 50 meters to a fault,

probably the same one which had been reached in the upper bed. From the face of the drift on the lower bed an opening was now driven up the dip, which gradually flattened, until the bed became horizontal at a distance of 20 meters and then gradually reversed its dip, thus defining an anticline. Along the crest of this anticline another drift was started parallel to the original strike-drifts. This drift progressed a distance of about 100 meters in regular coal and encountered no fault, although it advanced far beyond the line of the fault which had displaced the same bed on the limb of the fold. Moreover cross entries were driven down the dip to the right and left, and the persistence of the coal was proved to a point directly in the line of advance of the faulted drift on the limb of the fold.

At this stage of the work exploration was suspended and has never been resumed. All the advancing faces were in coal varying in thickness from about 2 meters on the crest of the anticline to 1 meter at a distance of 30 meters down the dip on either side. The coal is of superior quality, although somewhat crushed by the folding pressures. It appears that a fault had been avoided in this case with no great difficulty, and the exploration, although incomplete, is encouraging. However, the quantity of coal actually proved by this work cannot be placed at more than 10,000 metric tons.

The mine of the East Batan Coal Mining Company, situated on the eastern end of Batan Island, constitutes the most extensive coal exploration performed by Americans in the Philippines. This mine developed a 1.5-meter bed of coal over an area 1,100 meters long and 400 meters wide. The main entry was 500 meters in length, and one of the butt entries was 800 meters in length. All faces were in coal, and the bed was absolutely regular. A 7-centimeter parting, 45 centimeters from the roof, was maintained everywhere without variation. The only change in the character of the coal was noted in the workings farthest advanced to the west. At this point balls or lenses of hardened mud, containing pyrite, made their appearance in the coal. The company suspended operations for financial reasons and not because of any lack of coal in the mine. The East Batan coal is objectionable as a steaming fuel, because of its low calorific value and its tendency to slack, or disintegrate, in storage.

In summary, the exploration of Philippine coal beds may be said to show that the continuity of the coal is frequently broken by faulting; that by careful work the coal can usually be relocated beyond the faults without much difficulty or expense;

and that evidence of nonuniform conditions has been obtained in some cases, but that nowhere have large beds been shown to pinch out entirely by reason of the limited area of the original deposition. It is to be noted that the coals of higher quality are mostly faulted and that the lower grade coals are most regular. This is a condition which would be anticipated, since all the coals are of approximately the same age and only by more or less violent dynamism have the removal of water and the increase in the proportion of fixed carbon necessary to improve the quality been accomplished.

Judging from past experience, then, the development of Philippine coal fields must contend with minor faulting and the possibility of varying thicknesses of coal due to irregular original deposition.

ILLUSTRATIONS

TEXT FIGURES

FIG. 1. Plan of Esperanza gallery at the Compostela coal mine, Cebu, showing its passage through a fault, with sections across gallery at *a*, *b*, *c*, and *d*.

2. Sketch, showing in section exploration work on a 5-meter coal bed at Uling, Cebu.

3. Sections across 5-meter coal bed at Uling, Cebu. 1, section of outcrop of faulted coal; 2, section 10 meters beyond fault; 3, section 58 meters beyond fault; 4, section 84 meters beyond fault.

GEOLOGIC RECONNAISSANCE IN CARAMOAN PENINSULA, CAMARINES PROVINCE[1]

By Wallace E. Pratt

(From the Division of Mines, Bureau of Science, Manila, P. I.)

ONE PLATE AND 2 TEXT FIGURES

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INTRODUCTION

At the time the field work was performed for a geologic reconnaissance of southeastern Luzon,[2] it proved to be almost impossible to study the inaccessible region of Caramoan Peninsula except from a distance. In March, 1914, I had an opportunity to accompany a party from the Bureau of Forestry into this little-known area and to obtain general data as to its geologic constitution, thus extending proportionately the geologic reconnaissance map of Luzon Island. The accompanying topographic map (fig. 1) of Caramoan Peninsula was made by Arthur F. Fischer and Raphael Medina, foresters, Bureau of Forestry, in company with whom I worked, and is based upon Coast and Geodetic Survey charts.

GEOGRAPHY

Caramoan Peninsula, jutting toward the northeast from the southeastern peninsular portion of Luzon, forms a distinct physiographic province. The region is mountainous and of extreme relief. Roth[3] and von Drasche[4] quote Hochstetter's opinion

[1] Received for publication June 21, 1915.

[2] Adams, G. I., and Pratt, W. E., *This Journal, Sec. A* (1911), 6, 449 et seq.

[3] Roth, Justus, Ueber die geologische Beschaffenheit der Philippinen (1873), 333–354.

[4] Drasche, R. von, Fragmente zu einer Geologie der Insel Luzon (Philippinen). Wien (1878), 39.

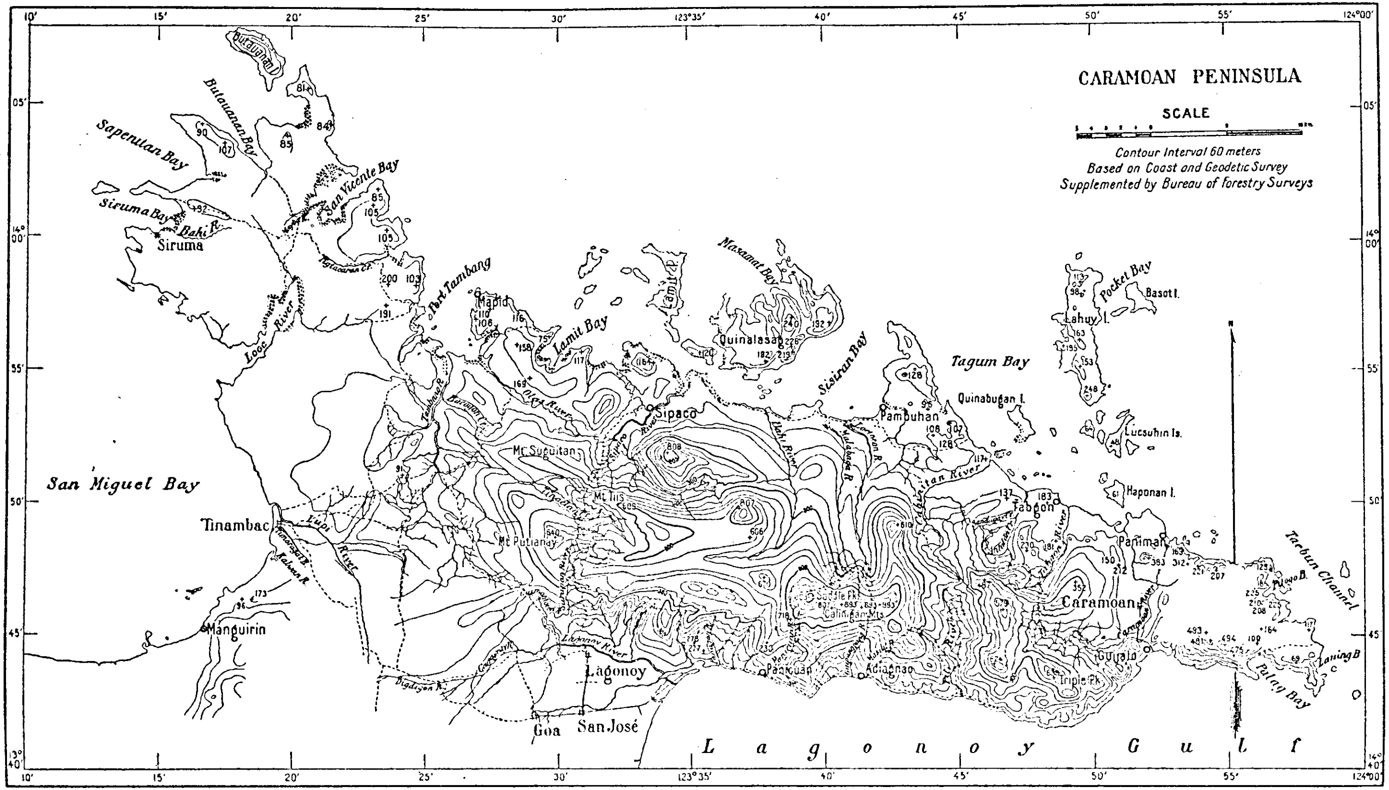

FIG. 1. Topographic map of Caramoan Peninsula, Camarines.

that Caramoan Peninsula was formerly an island and had been joined to the mainland of Luzon by deposits built up through eruptions of Isarog Volcano. The correctness of this conclusion is supported by the evidence of my reconnaissance work. Geologically Caramoan Peninsula is related to Catanduanes Island farther to the east rather than to the mainland, and the neck which connects the mass of the peninsula with the mainland consists of volcanic ejecta from Mount Isarog, younger in age than the rocks of the peninsula proper. The area is elongated in a west-northwest direction parallel to the main structural lines and contains approximately 600 square kilometers. The higher elevations, culminating in Saddle Peak (elevation 1,031 meters) in the Calinigan group of mountains, lie in the southern part of the peninsula, but extend west through the central portion. Mount Putianay, one of the prominent westernmost peaks, displays a white scar near its summit, which makes it conspicuous from the direction of the town of San Jose. The eastern end of the peninsula is rugged, but the hills attain only moderate elevations. The northern coast and the outlying islands are low and are fringed at places with swamps. The principal drainage systems discharge on the northern coast; no large river has developed so as to control the topography, but a series of short streams with tidal lower courses serve to carry away the run-off from an exceedingly heavy rainfall.

The peninsula is very sparsely inhabited, and a splendid forest covers its western half. The town of Caramoan near the eastern end of the peninsula was formerly larger than it is at present, and the forest has been cleared from much of the surrounding country. The forest yields a great deal of bejuco, a rattan used for binding hemp; the bejuco industry together with hemp planting and fishing are the principal industries. Some of the small islands to the north of Caramoan have been planted to coconuts, and the young groves are beginning to yield returns.

The southern coast of Caramoan Peninsula is regular and is bounded by straight lines; within a short distance from the shore the sea attains depths of 900 meters. The northern coast, in contrast, is sinuous, with numerous indentations, and the adjacent sea is shallow. Adams[5] has already pointed out the existence of a submarine shelf in this vicinity dotted with eminences which rise above sea level as small islands.

[5] Op. cit., 456.

GENERAL GEOLOGY

The greater part of Caramoan Peninsula consists of metamorphic rocks. Sedimentaries form the low-lying eastern end, and volcanics occur along the northern coast, but the conclusion that the central part of the peninsula is probably andesite, recorded in the reconnaissance already referred to, is in error. The rocks have been grouped as follows in the probable order of increasing age:

1. Alluvial and littoral deposits.
2. Isarog volcanic agglomerate and tuff.
3. Pliocene tuffs, flows, and agglomerates.
4. Tertiary sedimentaries } contemporaneous.
5. Metamorphic sedimentary rocks } contemporaneous.
6. Basal igneous complex.

The distribution of these formations is indicated on the accompanying geologic map (fig. 2).

ALLUVIAL AND LITTORAL DEPOSITS

Alluvial plains are developed over limited areas along the rivers at the town of Caramoan and the barrio of Parubcan. A larger area of mixed alluvial and littoral deposits is encountered in the vicinity of Lagonoy. These deposits are composed of surface detritus from the rocks of the various formations. The alluvium at Caramoan is largely clay and sand from the sedimentary series, while at Parubcan, where metamorphic rocks have been degraded, there is a larger proportion of gravel. At Lagonoy sand, clay, and gravel have been derived from the volcanic tuffs and agglomerates flanking Mount Isarog. Possibly some of the fragmental volcanic ejecta was thrown out late enough to have been interbedded with the recent alluvium. In the northeastern and northern parts of the peninsula there are mud flats largely covered at high tide, but there is little alluvium above sea level.

ISAROG TUFFS AND AGGLOMERATES

Mount Isarog is clearly an extinct volcano from which both flows and fragmental ejecta, uniformly andesitic in character, have been extruded in the past. The flows and the fragments in the agglomerates are porphyritic rocks with phenocrysts of calcic feldspar in a brownish, pumiceous groundmass. Many of the fragments in the agglomerate are partly rounded, so that the rock is in part a conglomerate of volcanic materials rather than a true volcanic agglomerate. The tuff, consisting of fine fragments of the same character as the flows, forms a cement

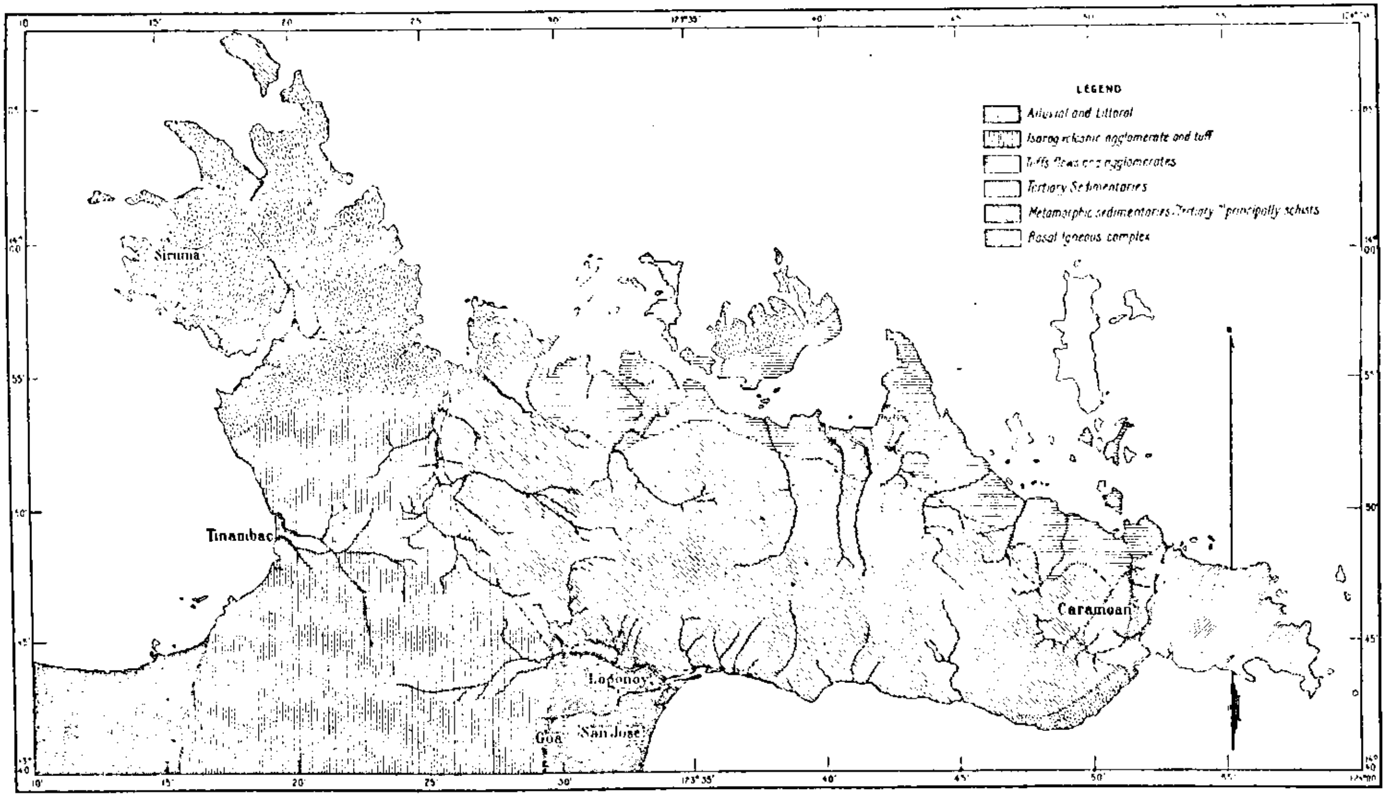

FIG. 2. Geologic reconnaissance map of Caramoan Peninsula, Camarines.

between the pieces in the agglomerate, but apparently does not occur as beds of exclusively fine-grained material. Part, at least, of the ejecta from Isarog is water-laid, but the formation is not bedded at any of the observed exposures. The series extends to the north as a veneer of gradually diminishing thickness over the metamorphic rocks.

Isarog Volcano belongs to a period older than the volcanic peaks to the south of it in Albay, one of which, Mount Mayon, is still active. It is probably younger than the tuffs and flows on the north coast of Caramoan, inasmuch as the latter are interbedded in part with the upper beds of the Tertiary sedimentaries, while the original distribution of the material from Isarog appears to have been influenced somewhat by the existing topography.

PLIOCENE TUFFS, FLOWS, AND AGGLOMERATES

The tuffs, flows, and agglomerates in the northern part of the peninsula are distinguished from the Isarog formation because of their probably greater age, their different character, and the complete segregation of the two formations in distribution. The northern series of volcanics consists of compact, perfectly bedded tuffs, tuff-sandstones, and intercalated, sheetlike flows, all of which are andesitic in character. In the region of the contact between this formation and the sedimentaries at the eastern end of the peninsula there are beds of limestone containing fragments of tuff in a series of strata which have also been pierced by domelike or pluglike intrusions of andesite and andesite-agglomerate. The series of tuffs, flows, and agglomerates is at least 100 meters thick. It lies nearly horizontal and forms low, grass-covered hills along the coast, but extends inland only to the base of the mountains.

TERTIARY SEDIMENTARIES

The sedimentary rocks in eastern Caramoan are a succession of limestones, shales, conglomerates, and fragmental or clastic sandstones. A single thin bed of coal is intercalated with the shales and sandstones. The thickness of the sedimentary series is undoubtedly not uniform, because the beds overlap progressively on the basal formation. However, the maximum thickness must be more than 500 meters. Intrusions of andesite and andesite-agglomerate have pierced the sedimentaries north of the town of Caramoan and again at Palag (or Apatag, as the name is rendered locally) Bay. The strike of the strata varies from north-northeast in the northern and western parts of the sedimentary area to west-northwest farther southeast;

the dips vary in steepness up to the vertical and in direction throughout the southern quadrants. There are at least three limestone horizons in the sedimentary column, but because of the complexity of the geologic structure, their exact position and thickness are undetermined. The succession of beds as indicated by the outcrops is contradictory in different localities, and therefore the presence of faults as well as frequent reversals of dip are suspected.

At the base of the series is a compact limestone, usually red, but also mottled gray at places. This limestone is very pure in some exposures, but elsewhere contains considerable clay and may even grade into calcareous shale. The lower limestone member is lacking in some sections, and conglomerates, clastics, and shale rest unconformably upon a basal formation of peridotitic rocks and fragmental derivatives, thoroughly jointed and metamorphosed.

The shale-sandstone-conglomerate member of the sedimentary column is not uniform in character. Exposures of black calcareous shale in thin, perfectly defined beds were observed in the river north of the town of Caramoan. Sandy yellow to brown shales and massive tuff-sandstone outcrop on the upper part of the same river southwest of Caramoan. It is here, also, that the bed of coal occurs. The horizon is higher than that of the thin-bedded shales to judge by the prevailing southwesterly dip. At Guijalo on the southern coast, and evidently in the base of the series, are fine conglomerates with rounded pebbles of various rocks, including some quartz, shale with calcite lenses between beds, and clastic or fragmental sandstones. The dip is westward, and farther east, on the opposite side of Guijalo Bay, a peridotitic basal complex is exposed, together with blocks of the lower limestone.

A gray, sandy limestone or calcareous sandstone, made up of perfectly defined, thin, hard beds alternating with thicker and softer layers, is included in the upper part of the sedimentary series. The most extensive exposure of this limestone is in the extreme southeastern part of the peninsula, where the beds dip to the south-southwest at angles of from 30° to 40°. The rock has been impregnated with silica, and the thin beds contain numerous concretions of black and gray chert. The intervening softer beds contain a considerable proportion of sharp fragments of tuff. On the surface in this vicinity are numerous pieces of iron-stained quartz, chalcedony, and silicified tuff. Small lenses of tarnished pyrite occur in the softer, thicker beds; these were apparently mistaken for copper minerals during the

Spanish régime. The limestone beds are so crumpled or corrugated at places as to take on an appearance of schistosity (Plate I, fig. 1).

Shale or sandstone, or both shale and sandstone, evidently intervene between the limestone just described and a heavy, upper limestone, to judge from the topography, but my observations were too limited to determine this point with certainty. At the apparent top of the sedimentary series, in any event, there is an extensive limestone member, coralline in origin, but now perfectly massive and partly crystalline. Splendid exposures are encountered in the high ridge trending east-southeastward to Palag Bay. Along the coast in this vicinity the limestone forms magnificent white cliffs, reaching an elevation of 200 meters and rising almost perpendicularly from deep water. On the north coast and also east of the town of Caramoan are hills of the same limestone.

Everywhere this limestone is fissured, and caverns have been formed through solution along the resulting joint planes. In one of the hills near Paniman there is a remarkable limestone cave or underground chamber, which is very aptly designated as "the cathedral" locally. The chamber is circular and has an area of approximately 2,500 square meters. The floor slopes rather steeply from south to north, and at the lower side is a large mass of rock fallen from the roof to precisely the position the altar would occupy in a real cathedral. Appropriately enough, the people of Paniman have surmounted it with a small crucifix. Three openings lead into the chamber, one at the back and one on either side of the altar, forming well-proportioned doors. In the domed roof, fully 30 meters above the highest part of the floor, there is an opening which serves admirably as a skylight. Numerous stalactites, each terminating in a point from which a glistening drop of water is suspended, hang from the arched walls, imparting a suggestion of Gothic architecture to the room.

It is reported that there are several small lakes in the limestone southeast of Paniman near the coast. The water in these lakes is said to be salty and to abound with sea fish. Evidently these lakes must communicate with the sea through subterranean passages.

METAMORPHIC SEDIMENTARY ROCKS

The mass of Caramoan Peninsula consists of metamorphic rocks—talc and mica-schist; schistose, massive rocks; and marble. The schists are evidently of sedimentary origin; indeed the original bedding planes are unmistakable, the planes

of schistosity being parallel to the bedding. The beds are much crumpled and distorted, but nowhere is the original stratification obliterated. I obtained an incomplete section of the metamorphic sedimentaries in the vicinity of Sabang, along a stream which flows into Lagonoy River from the north. The following succession of beds was encountered traveling inland from the coast; since the general strike is west-northwest and the dip is to the south-southwest, the first beds encountered are the youngest and represent the upper part of the series:

TABLE I.—*Geologic section north of Sabang.*

Stratum.	Approximate thickness.
	Meters.
Green schists, imperfectly bedded; compact, hard rocks	200
Fine-grained, homogeneous marble; gray to white	20
Thin fissile beds of talc-schist, schistose shale, and micaceous schists; green, yellow, and brown; quartz lenses along bedding planes	500
White and blue marble	2
Fissile beds of schist like above, but gradually passing into schistose, massive, light green or blue clastic rocks	800
White marble	5
Massive schistose fragmental rocks, light green to blue	([a])

[a] Undetermined.

I was unable to carry this section farther to the north because of the difficulty of penetrating the mountainous country; consequently I did not arrive at the base of the series. In crossing the peninsula from Lagonoy to Sipaco, I passed to the west of the line of the section just recorded and traversed, throughout nearly the entire width of the peninsula, bedded schists with quartz along the bedding planes. However, near the center of the peninsula, the strike of the beds changes from west-northwest to north-northeast, the dip swinging to the west, so that the width of the peninsula is greater than the length of a section across the schist formation. The westward-dipping rocks are less thoroughly metamorphosed than the schists and are clearly thin-bedded shale. On the north coast, also, there is an outcrop of metamorphic rocks, identical in appearance with the thin-bedded shale of the Tertiary sedimentaries, except for the metamorphism. These particular beds retain their original appearance unusually well, because of the fact that they have neither been distorted nor rendered schistose, but have been changed through induration and silicification only. The quartz lenses along the bedding and schistosity planes in the schist

conform to the wrinkling in the beds without any evidence of having been shattered; hence they must have been introduced after the crumpling had been accomplished. Lenses of pyrite are found in the upper part of the green schists much like the lenses of the same mineral in the sandy limestone or calcareous sandstone member of the sedimentary series.

BASAL IGNEOUS COMPLEX

Altered black rocks which appear to be of the subsiliceous igneous type, probably peridotites, are exposed on the southern coast of the peninsula at the base of the sedimentaries. They are closely jointed in several directions and are thoroughly indurated. Hand specimens reveal little except the presence of serpentine. A mantle of closely derived fragmental rock, which is also metamorphosed, obscures the true character and relations of these basal rocks. In the outlying islands north of Caramoan, also, the basal rocks are exposed, and there gneissic diorite is prominent in the igneous complex.

There is a limited area of fresh diorite on the south coast near the point between Guijalo and Parubcan. Likewise there is diorite in the vicinity of Mapid and around Tambang Bay on the north coast. These rocks are holocrystalline, of medium grain, and consist essentially of hornblende and calcic feldspars. At both places the exposures form part of the basal complex into which the diorite is probably intrusive. In the outcrop at Mapid there are a number of veinlets containing chalcopyrite and pyrite, together with quartz and some calcite.

Along the eastern coast of the region northwest of Tambang Bay there is a continuous exposure of a black, igneous-appearing rock which, from its general appearance, I believe to be peridotic in character. Both my trips along this coast were made in rough weather in a small boat; consequently I had little chance to examine the outcrops. Specimens which I secured were lost subsequently when my boat capsized. If the rock is peridotite, it is undoubtedly to be correlated with the peridotite farther west in the Paracale mining district, and the Paracale peridotite is probably the equivalent of the metamorphosed peridotic rocks in the basal complex upon which the Caramoan sedimentaries were deposited. Upon this basis the region northwest of Tambang Bay is mapped as part of the basal igneous complex. It may be, however, that the rock in question is a massive flow related to the tuff-agglomerate-flow series. Certainly it has less appearance of metamorphism than the average basal-complex outcrop.

On the western end of the peninsula, bordering San Miguel Bay, there is an area of light-colored schistose porphyry, which was identified as schistose andesite by Smith.[6] This rock is grouped with the basal igneous complex in this preliminary study, but there is no certainty that it is as old as the basal rocks.

CORRELATION

Mount Isarog is one of the older of the extinct volcanoes in the Philippines. Mount Mariveles, near Manila, is usually taken as the type of these older volcanoes, the lavas of which were more siliceous than the ejecta from the subsequently active volcanic centers. The activity of Mount Mariveles, according to Smith,[7] began in Pliocene time and continued into the Pleistocene; a corresponding age may be assigned to the Isarog ejecta.

The tuffs, flows, and agglomerates on the northern coast appear to be in some degree contemporaneous with the upper part of the Tertiary sedimentaries, assuming that the tuff observed in the limestone beds near the top of that series is related in origin to the tuff of the volcanic formation. In Cebu there are tuffs and flows immediately beneath the limestone, which Abella[8] fixed as Post-Pliocene. Tuffs, flows, and agglomerates similar in appearance to those in Caramoan and probably of corresponding age are found in the Laguna de Bay region east of Manila. Without much question these various occurrences may be correlated and placed in the Pliocene or upper Miocene.

The upper part of the sedimentary series corresponds roughly with the limestone, sandy limestone, and clay-tuff at the top of the sedimentary rocks in the petroleum fields of Tayabas and Leyte.[9] The work in Tayabas fixed this general horizon as upper Miocene and Pliocene. The shales and associated rocks in the lower part of the sedimentaries may be correlated directly with similar rocks elsewhere. The coal horizon and the underlying thin-bedded shale are recognized characteristics of the Philippine Tertiary. In the basal limestone of the Cebu series I found fossils which Smith[10] identified as *Heterostegina margarita*

[6] Dr. Warren D. Smith made a petrographic study of the rocks collected during the field work for the reconnaissance of southeastern Luzon, which included this rock.

[7] *This Journal, Sec. A* (1913), 8, 235 et seq.

[8] Abella y Casariego, Enrique. La Isla de Cebu. Imprenta y Fundición de Manuel Tello, Madrid (1886), 120.

[9] *This Journal, Sec. A* (1913), 8, 301 et seq. Ibid. (1915), 10, 241.

[10] Ibid. (1914), 9, 157.

Schlumberger (Oligocene?). Therefore the sedimentaries are not older than the Oligocene.

The metamorphic sedimentaries exhibit a succession of beds identical in its main features with the Philippine column of Tertiary sedimentaries. The observed sections in the metamorphosed sedimentaries and in the unchanged sedimentaries farther east are similar, although the lower part of the metamorphosed section is developed in greater thickness than the corresponding division of the unchanged rocks. Moreover, in ascending Caramoan River, one passes gradually from unchanged sedimentaries to metamorphosed sedimentaries: that is to say, there is an evident transition from one formation to the other with no definite line of contact.

In short, the schists and marbles appear to be no older than the shales and limestones. Indeed these rocks appear to be different sections of continuous beds which have been metamorphosed in their westward extension but have escaped metamorphism farther east.

Thus the schists and marbles are likewise not older than the Oligocene, and the antiquity which has been ascribed to the metamorphic rocks generally in the Philippines is opened to question. Paleozoic schists are found in Japan and in Formosa, and they may exist in the Philippines, but the extensive area of more or less typical schists on Caramoan Peninsula belongs to a later period.

The basal igneous complex upon which the Tertiary beds were laid down obviously antedates these beds, but its age cannot be more definitely fixed. The age of the schistose andesites, grouped for convenience with the basal igneous complex, is likewise undetermined.

GEOLOGIC HISTORY

The geologic history of Caramoan Peninsula, so far as it may be deduced from the data in hand, begins with an eroded pre-Oligocene basal formation, principally a complex of igneous rocks. From Oligocene time through to the Pliocene this basal formation was submerged, and sedimentary rocks were laid down over it. Whether each division of the sedimentaries is strictly conformable over the preceding deposits is not certain, but no unconformities were observed. The metamorphic andesite in the western part of Caramoan was introduced, presumably as a flow, during or preceding the deposition of the sedimentary rocks.

Dynamism, severe enough to change the sediments into true

schists, succeeded the period of sedimentation. This dynamism affected most strongly the central and western parts of the peninsula and left the sedimentaries at the eastern end unmetamorphosed. The rocks converted into schist have not lost their original bedded structure. The igneous basement upon which the sediments lie has not been rendered thoroughly schistose, but this is probably because the igneous rocks were less responsive to dynamic action than the bedded rocks. Just what form the dynamism assumed is undetermined. Adams [11] concluded that Caramoan Peninsula had suffered a severe thrust from the Pacific (northern) side and perhaps this is the true explanation. Certainly the strata have been forced into folds along a predominatingly west-northwest line, and over comparatively extensive areas the sedimentary and metamorphic rocks are inclined at steep angles southward.

Subsequent to the period of metamorphism quartz was introduced along bedding planes and fractures, forming quartz lenses in the schists and concretions of chert locally in the unmetamorphosed limestones. Perhaps the observed pyrite lenses and the veinlets of pyrite and chalcopyrite are related to this activity also. The volcanism which produced the tuffs, flows, and agglomerates of andesite along the northern coast began toward the end of the period of sedimentation, but belongs essentially to a later time. Finally came the extrusion, which built up Mount Isarog and joined Caramoan to the mainland of southeastern Luzon.

During recent times erosion and the submergence evidenced by the drowned appearance of the north coast have been the principal factors in modifying the contour of Caramoan Peninsula. The recent submergence has permitted the Pacific to advance on the land, drowning the rivers and submerging, except for the highest points which remain as islands, a considerable area that formerly extended to the north from Caramoan Peninsula. At present the submergence is no longer in progress, but to judge from slightly raised beaches along the north coast, elevation has once more begun.

ECONOMIC GEOLOGY

GENERAL

Caramoan Peninsula is important principally on account of its forest resources. Neither agriculture nor mineral industries have become prominent on the peninsula proper, although hemp

[11] *This Journal, Sec. A* (1911), 6, 469.

and sugar planting are remunerative in the vicinity of Mount Isarog.

The alluvial and littoral deposits support the larger part of the population. These formations and the Isarog tuff and agglomerate yield rich soils and lend themselves to agricultural development. The volcanics on the north coast, on the contrary, appear to support little vegetation. No attempt has been made to cultivate this part of the peninsula, but in place of the heavy forests which abound in some other parts of the area the natural vegetation on the tuffs and flows consists principally of hardy cogon grass. There is no evidence that this region ever was forested. The sedimentary rocks are also comparatively barren of vegetation. However, the original forest has been cut away over the sedimentaries, permitting the cogon grass to replace it. Except for the crystalline limestone this formation should disintegrate rapidly enough and form a fairly good soil. The metamorphic rocks appear to yield good soils in spite of their induration; at any rate, they support a splendid forest growth. The Caramoan forest concession, which is considered to be particularly valuable, covers principally metamorphic rocks and the Isarog tuff-agglomerate formation. The unaltered igneous rocks, again, are comparatively barren; cogon grass and a small evergreen tree, said to be a variety of "iron wood," mark the igneous exposures.

GOLD

The quartz lenses in the schists carry a trace of gold; so, also, do the pyrite lenses. But there is no evidence of valuable gold deposits on Caramoan Peninsula. Becker[12] was led to the conclusion that "in all cases in the Philippines of which the details are known, crystalline schists accompany gold-quartz veins, copper ores, iron ores, and galena." If this condition really existed, it might be assumed, conversely, that an area of crystalline schists would be likely territory for the gold prospector, but the case of Caramoan Peninsula does not bear out this conclusion. As a matter of fact, subsequent work has shown that some of the more important gold deposits in the Philippines are not related to the crystalline schists. Moreover Becker believed most of the Philippine crystalline schists to be of comparatively great age and had in mind such older crystalline schists. Therefore the Caramoan schists, being geologically young rocks, would not be expected by Becker to contain gold.

[12] Becker, George F., *21st Annual Rept. U. S. Geol. Surv.* (1901), 237, reprint.

COPPER

Enrique D'Almonte's map of Luzon (1883) indicates copper at two places near the eastern end of Caramoan Peninsula. Jagor [13] states that he saw metallic copper which came from a place north of Patag (Palag) Bay, in the vicinity, apparently, of the mines indicated by D'Almonte. The people of Lagonoy remember a Frenchman who mined for copper north of that town about thirty years ago. Becker quotes Roth to the effect that Caramoan Peninsula is probably composed of crystalline schists, judging by the reported occurrence of copper there.

I found no copper at the points indicated by D'Almonte, although I was conducted to the supposed mines twice, each time by a different guide. But I did find on each occasion the tarnished pyrite lenses to which I have already referred. These are found not in schists in eastern Caramoan, but in calcareous sandstone. They are apparently the only basis for the reported copper discoveries. Jagor would not have mistaken this mineral for copper, but it is very doubtful if the copper shown to him came from Caramoan Peninsula. At the place north of Lagonoy, where the Frenchman is supposed to have worked, similar pyrite lenses abound, and in this case they really occur in schist, as Roth supposed of the copper, but no copper minerals accompany them.

The only copper I saw on Caramoan Peninsula occurs as the mineral chalcopyrite in veinlets in diorite near the barrio of Mapid. The deposit at this place is of no economic importance.

MERCURY

The presence of metallic mercury on Mount Isarog has repeatedly been affirmed by the people near that mountain and has been reported to both the Spanish and American mining offices. The reports are persistent, and it is beyond question that the primitive people (Negritos) living on the upper slopes of Mount Isarog are acquainted with the physical properties of mercury. I found that they could describe it accurately, even though they considered it to be a valuable medicinal charm. But I was unable to find any mercury or even cinnabar myself. My guide, a Negrito, assured me that it was very scarce, and recommended that I would do better to come again at a more favorable time. All Saints Day, he thought, would be best, and then if I were very lucky and followed a certain stream from mouth to source, I might find a little mercury which would shine, he said, from

[13] Jagor, F., Reisen in den Philippinen. Wiedmann'sche Buchhandlung, Berlin (1873), 145.

the bottom of some pool. Solfatarism is common on Isarog, and the presence of mercury in the vicinities of some of the solfataras is not impossible.

COAL

There is an outcrop of coal in the sedimentary rocks along Caramoan River about 2 kilometers upstream from the Guijalo-Caramoan road. The outcrop has been known for at least seventy years. The bed is about 50 centimeters thick, and the coal is a dirty black lignite. The strike is nearly north, and the dip is westward at a high angle. Isidro Sainz de Baranda, the first inspector of mines under the Spanish régime, and a capable man, believed the coal from this outcrop to be of good quality. No tests have been made of it, but its appearance is not promising, and the outcrop indicates too thin a bed to be commercially important. Several concessions for this coal were sought in Spanish times, and in 1898 a concession was finally granted, but title was never perfected under the American laws. The vicinity of Guijalo was formerly known as Puerto de Minas in anticipation of its importance as a shipping point for this coal.

I was informed that coal had been found in the hills near the barrio of Parubcan and was shown a specimen of good coal which was alleged to represent the outcrop. I was unable to find the coal in place, however, even with the assistance of several guides. If the beds of schist at Parubcan inclose coal, it should be a coal of good quality because of the metamorphism it must have undergone.

CLAY

The light-colored talc-schists in the vicinity of Lagonoy are used as paint clay in the neighboring towns. The paint is grayish white and adheres tenaciously to wood. A good white clay is obtained at a place called Sulpa on Looc River, between Tinambac and Siruma, in the northeastern part of the peninsula. This clay appears to result from the decomposition of quartz-feldspar rocks which occur as dikes in the schistose andesite. The clay is plastic, although in the crude state it contains fragments of quartz, and should make a fair grade of pottery or refractory ware.

STONE AND GRAVEL

Possibly some of the marbles and limestone on Caramoan Peninsula could be exploited for construction purposes. The marble in the vicinity of Sabang is most conveniently located, and if there were a demand for it, could be quarried advantageously.

A heavy, dense, dark-colored schist from northwest of Lago-

noy is used by the Filipinos to manufacture whetstones for sharpening bolos. The stone appears to serve this purpose very well, but the demand for whetstones is not great enough to make the manufacture steady or profitable.

At several places along the southern coast, between Sabang and Parubcan, there are extensive beaches of perfectly rounded gravel of sizes suitable for use without reduction in road building. The pebbles are of hard metamorphic rocks, and while they tend to assume flat rather than spherical forms, they should make a superior road metal.

ARTESIAN WATER

Only a few wells have been drilled on Caramoan Peninsula, but the drilling campaign which the Bureau of Public Works is carrying on will ultimately extend to this region, and the possibilities of obtaining artesian water should be considered.

The metamorphic and igneous rocks on Caramoan Peninsula will probably be found to be comparatively dry. If no water is obtained from the first or second test-well in these formations, no more wells should be drilled into them. The tertiary sedimentaries have been shown by experience elsewhere to be usually barren of artesian water. Therefore they will probably also be dry in Caramoan Peninsula. The volcanic tuffs and flows on the north coast may possibly yield artesian water, but they offer little promise; in general, they are too close-grained to yield strong flows.

There remain the alluvial deposits and the Isarog tuffs and agglomerates. Both these formations are undoubtedly water-bearing and with proper care should be made to yield potable water from comparatively shallow wells. The Isarog formation may contain mineralized water at places and may require deeper wells than the alluvium. The alluvium on which Caramoan lies should receive attention when wells are drilled for that town. It should be saturated above the sedimentary floor on which it rests, and a series of shallow wells should meet the requirements of this town. If they do not, there is little hope of obtaining water, because the underlying sedimentaries are almost certainly not water-bearing. Likewise the areas of alluvium overlying the metamorphic rocks should be tested in advance of the metamorphics themselves.

The prospects for artesian water are fairly good, then, at the towns of Caramoan, San Jose, Sabang, Lagonoy, Goa, and Tinambac; but elsewhere, except within alluvial areas or the Isarog volcanic formation, artesian water will probably not be obtained.

ILLUSTRATIONS

(Photographs by Pratt.)

PLATE I

FIG. 1. Crumpled thin-bedded limestone near Palag Bay.
2. Sinuous quartz vein in schist near Sabang.
3. Weathered outcrop of marble in schist near Sabang.

TEXT FIGURES

FIG. 1. Topographic map of Caramoan Peninsula, Camarines.
2. Geologic reconnaissance map of Caramoan Peninsula, Camarines.

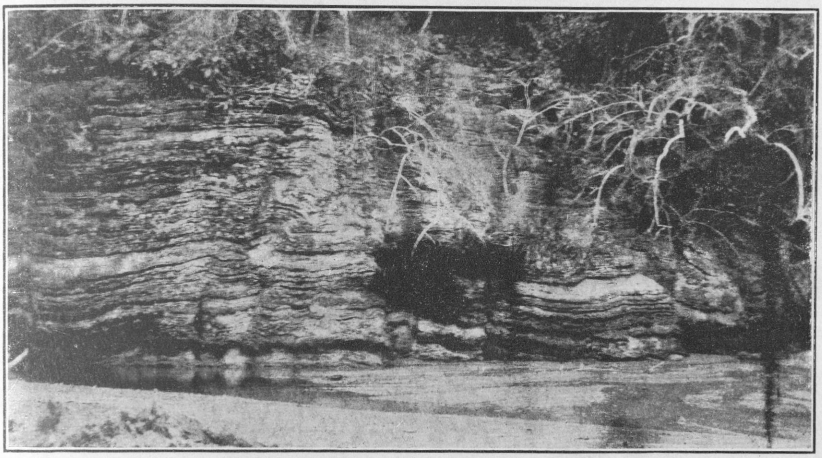

Fig. 1. Crumpled thin-bedded limestone near Palag Bay.

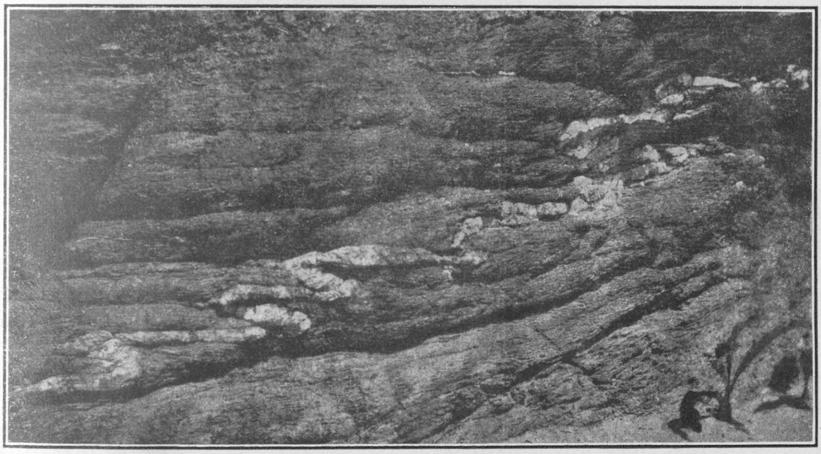

Fig. 2. Sinuous quartz vein in schist near Sabang.

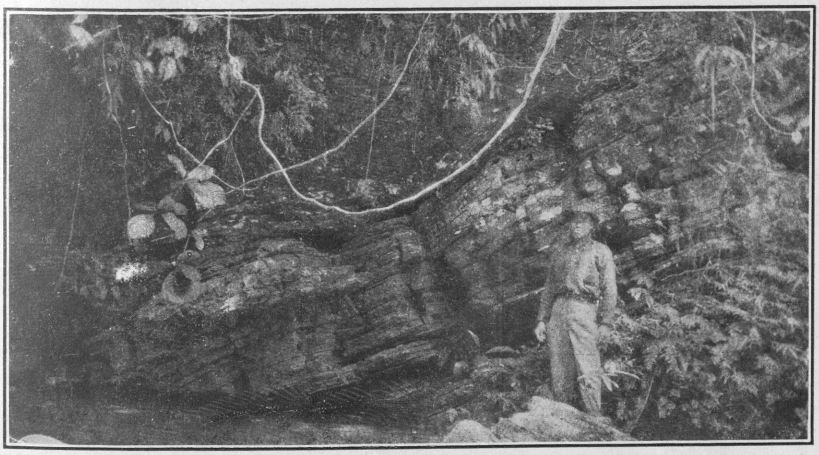

Fig. 3. Weathered outcrop of marble in schist near Sabang.

PLATE I.

IRON ORE ON CALAMBAYANGA ISLAND, MAMBULAO, CAMARINES [1]

By WALLACE E. PRATT

(From the Division of Mines, Bureau of Science, Manila, P. I.)

TWO TEXT FIGURES

SITUATION

The Calambayanga iron-ore deposit is situated on the western part of Calambayanga Island and on the adjacent mainland over an undetermined distance. Calambayanga is the name by which the Coast and Geodetic Survey designates a small island in Mambulao Bay on the north coast of Camarines Province, southeastern Luzon (fig. 1). The name is more commonly rendered

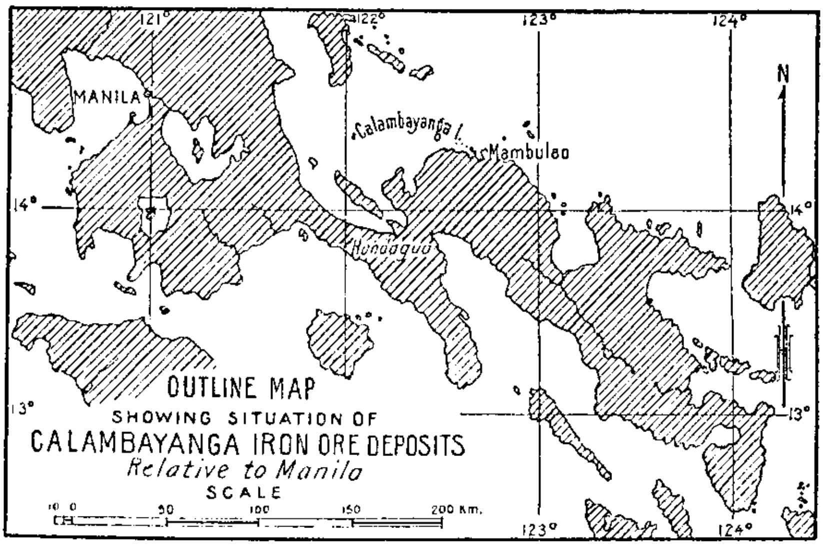

FIG. 1. Showing situation of Calambayanga Island, Camarines Province.

Calambayunga by the local inhabitants. Mambulao Bay is 185 kilometers (115 miles) in a straight line directly east of Manila. The usual sailing route for steamers encircles southeastern Luzon and is about 900 kilometers (560 miles) long. By combined railroad and steamship routes the distance is not much longer than a straight line from Manila to Mambulao.

Calambayanga Island is a little more than 1,100 meters (0.7 mile) in length with a maximum width somewhat greater

[1] Received for publication April 23, 1915.

than half its length. It is elongated in a north-south direction, and attains an elevation of 70 meters (230 feet). The island is separated from the mainland to the south of it by a stretch of shallow water about 500 meters (1,600 feet) wide. Text figure

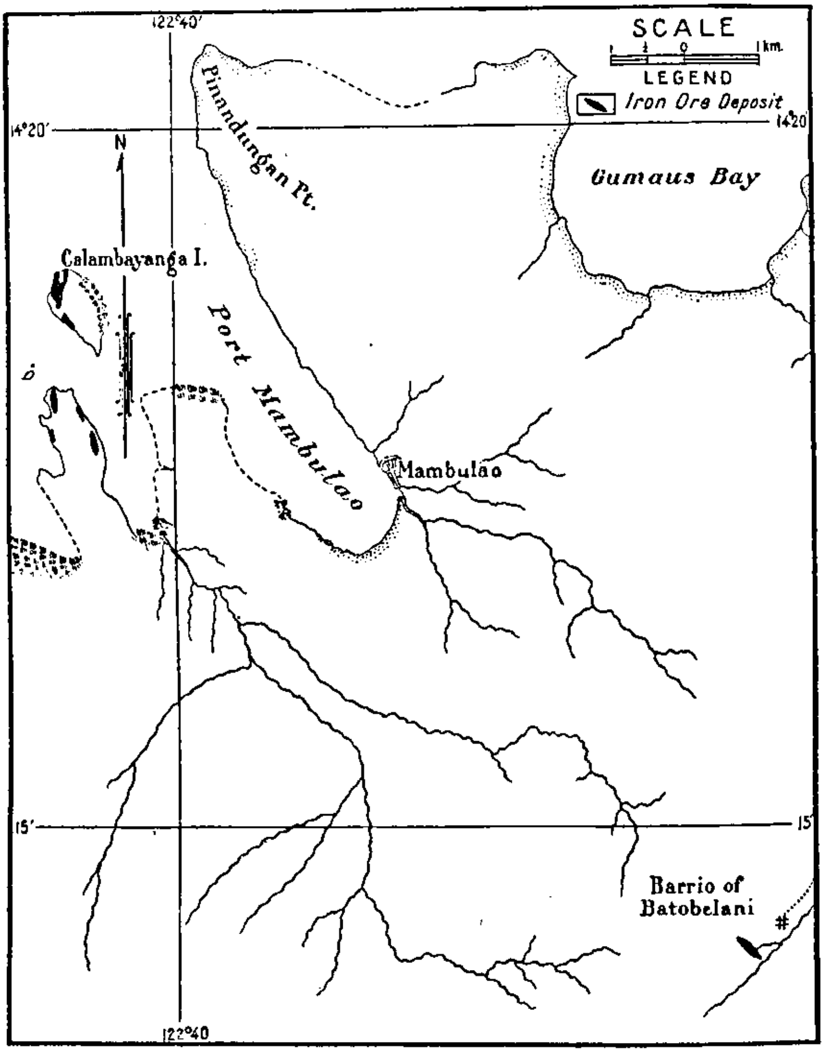

FIG. 2. Showing the location of the Calambayanga iron-ore deposits, Camarines Province.

2 shows the general situation of Calambayanga Island. Off the northwest point of the island the sea has a depth of 10 meters (33 feet) within 100 meters of the shore line, and a depth of 7 meters (23 feet) persists to within 50 meters of the western shore line. By utilizing small outlying reefs to the

north, in the construction of a short breakwater, it would be possible to make a small secure harbor at this point with no great expenditure. Dahikan Bay, 4 kilometers (2.5 miles) to the east of Calambayanga Island, is charted as a safe anchorage by the Coast and Geodetic Survey.

Fresh water is to be had only in limited quantity on the island itself, but could be obtained in abundance on the adjacent mainland. There are several small springs on the island, and in the rainy season these give rise to a small stream.

HISTORY

Concessions for iron mines on Calambayanga Island were sought repeatedly during the Spanish control of the Philippine Islands, but there is no record that any was granted. The iron ores in the Eastern Cordillera of Luzon were known and exploited in the seventeenth century, and probably the deposit on Calambayanga Island was discovered at a similarly early date. It is probable that Filipino iron smelters were operated at the Calambayanga deposit, as they have been in Bulacan Province, since pieces of slag and inclosed charcoal much like the Bulacan slags have been found near Mambulao by Mr. A. C. Cavender, the present owner of the Calambayanga ores.

GENERAL GEOLOGY

The Calambayanga iron ore lies at the western border of the Paracale gold field, which has been productive for three centuries and at present yields nearly 50 per cent of the total gold production of the Philippines. The gold appears to be associated with granite, which is intruded into more basic rocks—diorite and peridotite; the gold is found in veins which formed in the granite and the surrounding rocks after the solidification of the intrusion. To the west and southwest of and overlying the granite and diorite area is a series of sedimentary rocks younger than the granite and probably of Miocene age. The iron ore is found in the base of these sedimentaries, which include sandstones, conglomerates, shales, tuffs, and minor limestones. All the rocks in the district have been metamorphosed by regional dynamic action, and the sedimentary rocks have been pierced by dikes and overspread by flows and agglomerates. Probably the dynamism which rendered the granite gneissic and the diorite schistose over the whole district and indurated, folded, and faulted the sedimentary beds was accompanied or followed by the extrusions, which are andesite. The fractures

which were formed in the granite during metamorphism were filled by gold-bearing quartz. One of the products of the mineralization associated with the intrusion of the dike rocks into the sedimentaries is the iron ore in question.

CHARACTER OF THE IRON-ORE DEPOSITS

The ore body on Calambayanga Island appears to be irregular in shape, but to conform more or less closely to the strike and dip of the sedimentary beds in which it occurs. It outcrops on the western part of the island and is roughly oval or lens-shaped in plan. Ore of exactly the same character is encountered on the mainland to the south, where exposures are seen at intervals for a distance of at least 2 kilometers (1.2 miles) inland. A small island south-southwest of Calambayanga Island and considerably to the west of a line between it and the outcrops on the mainland is composed wholly of iron ore of the same character. Again, at Bato-bolani, 12 kilometers (7.5 miles) southeast of Calambayanga Island and still near the line of contact between the sedimentaries and the older igneous rocks, iron ore similar in character to the Calambayanga ore is found.

At each of these places the outcrops are marked by great blocks of black ore, angular in form and with pitted, irregular surfaces. These blocks have been designated as bowlders by several observers, but the term bowlder conveys a wrong impression, inasmuch as the masses of ore at the outcrops show no evidence of having been transported, but have the appearance of disintegration products in place. They vary in size up to masses of many tons' weight. At the prominent outcrops they occur to the exclusion of all other rocks, but elsewhere they are isolated from each other and are embedded in yellow, residual clay.

Only the Calambayanga ore body has been examined closely by me. The western half of the island is strewn with blocks of ore. The northeastern part is made up of sedimentary rocks, principally sandstones, or fine-grained clastics, shales, and conglomerates. At the northern extremity of the island the beds strike north 20° east and dip 45° to the west, but toward the south, along the east coast, the strike changes gradually until it is north 60° west with the dip to the south. A bed of crystalline limestone outcrops in the sedimentaries halfway along the eastern coast, and some of the other sedimentary beds are calcareous. Minor outcrops of stratified rocks are found on the eastern coast, but here the strike is north 60° west, and tuffs, agglomerates,

and fragmental rocks predominate over other types. These volcanic rocks are less indurated than the sedimentaries on the eastern shore of the island, and there is a consequent suggestion that they belong to a separate younger formation.

Extending north-northwest into the mass of the island from the southeastern point is a great outstanding body of quartz, a lode or vein, with a width of possibly 100 meters. This quartz is mineralized and contains numerous veinlets of iron ore. A shallow pit has been sunk in the quartz near the center of the island, and a sample taken from the wall of this pit showed upon assay a trace of gold. The sedimentary rocks to the east are highly silicified near the contact with the quartz.

The outcrop of the quartz becomes concealed toward the north-northwest by a mantle of clay, but on the northwest shore, approximately at the point where the quartz should reappear, if it continued so far, there is encountered a dike of dark-colored gabbro between agglomeratic tuff and sedimentaries. This dike is vertical and strikes north 60° west. A small vein of quartz carrying unaltered fresh pyrite was observed in it. Under the microscope the dike rock is seen to be holocrystalline and to consist principally of plagioclase feldspar and pyroxene. The feldspar predominates and occurs in large lath-shaped crystals with a parallel arrangement. The pyroxene appears to be much decomposed, and associated with it throughout the section is magnetite in considerable abundance.

Along the western and northern shore line of the island the blocks of iron ore are present in great abundance and lie one upon another with no intervening foreign material. Farther up the slopes, however, and at the summit of the island the blocks are scattered over the surface, embedded in residual clay.

Fanning [2] studied the ore on the mainland; he traced the outcrop of the ore for a total distance of 3 kilometers (including the outcrop on the island?). The width as revealed to him by occasional outcrops in place varied up to 15 meters. Sedimentary rocks are found on the mainland, as on the island, and similarly are indurated, tilted at various angles, and pierced by dikes. Volcanic tuffs, agglomerates, and flows are prominent on the mainland and on the neighboring small islands.

At Bato-bolani the iron ore occurs in large blocks scattered over the side of a hill. The ore is magnetite with some hematite and carries also fresh quartz and pyrite. F. Rinne,[3] a German

[2] Smith, W. D., and Fanning, P. R., *Min. Res. P. I. 1910* (1911), 58.

[3] *Zeitschr. f. prak. Geol.* (1902), 10, 117.

geologist has published a description of the Bato-bolani ore deposit from which the following extract is quoted:

It might be thought that the magnetite masses here are a segregation from an igneous rock, probably from the diorite found between the masses of ore. It is surprising, however, in explaining the magnetite as a magmatic segregation that nowhere was the contact between the diorite and the ore to be seen. The ore masses were encountered everywhere without any adhering or inclosed pieces of diorite. This circumstance indicates strongly that the once existing rock with which the present blocks were associated was comparatively easily destroyed, so that the ore, freed through weathering, is now nowhere in continuity with it. In this connection the occurrence of a dark-colored limestone, of which several pieces were found at a place on the same slope, is interesting. It is possible that the ore masses were enveloped in this easily soluble limestone. It appears to me very plausible that the magnetite blocks at Bato-bolani were formed by contact phenomena between diorite and the limestone, which is still found in traces over the former surface of the igneous rocks. * * * One could suppose that the ore formed in the limestone under the influence of the solutions and gases coming from the cooling diorite magma. I did not observe other contact minerals such as garnet, at the place, but in complete accordance with this theory is the occurrence of nests of yellowish white, needlelike quartz which are found sparingly in the magnetite. In places the ore particles build a sort of frame or skeleton, the spaces of which are filled with quartz.

CHARACTER OF THE ORE

The iron ore on Calambayanga Island and on the adjacent mainland is almost pure hematite with only traces of magnetite. The hematite is massive or granular, and the ore is moderately soft and very porous, or vesicular. At places over the exposure a small proportion of pyrite in fresh crystals may be detected in the hematite, and likewise quartz is found sparingly in scattered grains or in veinlets. Copper stains were found in the slightly pyritiferous ore at two places, indicating that some chalcopyrite occurs with the pyrite.

The Bato-bolani ore contains much more magnetite than the ore on Calambayanga Island; it is also harder and shows more pyrite and quartz, but otherwise the ores are similar.

The composition of the ore is shown in Table I. Analysis 1 is to be given greater weight than any of the others because of the larger quantity of ore which it represents. Apparently the average ore carries about 60 per cent of iron and is reasonably free from objectionable constituents. In only one analysis is the phosphorus above the Bessemer limit.

GENESIS OF ORE DEPOSIT

The observations set forth in this report have led to the conclusion that the ore on Calambayanga Island is related in origin

TABLE I.—*Analyses of iron ores from Calambayanga Island.*

[Figures give per cent.]

Constituent.	Sample.					
	1	2	3	4	5	6
Silica (SiO_2)	1.02	1.29				8.71
Alumina (Al_2O_3)	1.31	6.52				
Ferric oxide (Fe_2O_3)	97.35	68.28				
Ferrous oxide (FeO)		9.22				
Lime (CaO)		2.77				
Magnesia (MgO)		0.29				
Manganese (MnO_2)	0.11	0.09				
Phosphorus (P)	0.001	0.10	0.001	0.005	0.008	0.035
Sulphur (S)		0.12	0.138	0.07	0.067	trace
Total iron (Fe)	64.14	54.96	57.11	63.69	46.06	65.76

1. Calambayanga ore: Average composition of a sample of 200 kilograms (440 pounds) of representative ore from Calambayanga Island. Analysis by T. Dar Juan, chemist, Bureau of Science.

2. Calambayanga ore: Hand specimen; analysis by Forrest B. Beyer, formerly chemist, Bureau of Science.

3. Calambayanga ore: Sample taken by P. R. Fanning, formerly assistant, division of mines, Bureau of Science, representative of many blocks of ore along entire outcrop on Calambayanga Island. Analysis by T. Dar Juan, chemist, Bureau of Science.

4. Calambayanga ore: Sample taken by P. R. Fanning, formerly assistant, division of mines, Bureau of Science, from many blocks of ore over a distance of 500 meters on mainland near Calambayanga Island. Analysis by T. Dar Juan, chemist, Bureau of Science.

5. Calambayanga ore: Sample taken by P. R. Fanning, formerly assistant, division of mines, Bureau of Science, on Calambayanga Island from a single lump specimen. Analysis by T. Dar Juan, chemist, Bureau of Science.

6. Bato-bolani ore: Hand specimen taken by H. M. Ickis, formerly assistant, division of mines, Bureau of Science; analysis by H. S. Walker, formerly chemist, Bureau of Science.

to the quartz vein or lode with which it is associated. Veinlets of ore are found in the quartz, and quartz occurs sparingly in the ore. The processes which produced the body of quartz probably yielded under different local conditions the adjacent body of iron ore. Both types of mineralization probably resulted directly or indirectly from the intrusion of dikes into the sedimentary rocks near the contact with the older igneous base. Apparently there was some replacement of the wall rocks as well as the filling of cavities and fractures. Probably the limestone and the calcareous sediments were most susceptible of replacement in this manner. The dike of gabbro on the northwestern shore of the island with its notable proportion of magnetite may be taken to represent a part of the intrusive rocks. The tuff and agglomerate on the shore of the island and on the neighboring islands and mainland are surface extrusions which may be related genetically to the dike rocks.

Rinne concluded that the Bato-bolani ore had resulted from

contact mineralization, probably at the contact of intrusive diorite and limestone. The Bato-bolani and Calambayanga ore deposits prove upon examination to be very much alike, except that magnetite is the predominant ore mineral at Bato-bolani, whereas hematite predominates at Calambayanga. Probably the two deposits are related in origin, and certainly the observations recorded herewith on the Calambayanga deposit are evidence of a genesis similar to that suggested by Rinne for the ore at Bato-bolani.

Certain general characteristics are common to the iron ore at Calambayanga, at Bato-bolani, and in Bulacan Province:[4] for example, the association of the ore with intrusive rocks in sedimentaries, especially limestones; the nature of the ore minerals; and the presence of quartz in the ore. In some of the Bulacan deposits the replacement of limestone by ore is clearly evident.

QUANTITY OF ORE AVAILABLE

No development work which throws any light on the dimensions of the deposit nor the persistence of the ore with depth has been done on the Calambayanga ore. The only direct evidence which can be brought to bear in a discussion of quantity is the extent of the outcrops. But even the dimensions of the outcrop cannot be determined accurately because of the fact that the ore is encountered only in blocks which afford no precise data as to the width of the ore in place. The size and abundance of these blocks and the length of the line along which they occur have led several observers to the conclusion that they represent an ore body, or ore bodies, of great size. Fanning,[5] for instance, concluded:

> The quantity of hematite cannot be estimated at the present time because experience in other fields where enormous quantities were indicated on the surface shows that they may not be realized at depth. Whether or not this will be true for this formation is a matter for future development to determine. * * * The surface indications are excellent, yet the amount and quality of the ore are unknown. It is unquestionable, however, that the property is worthy of extensive development.

Adams, also, examined the Calambayanga deposit and commented on it as follows:[6]

> A deposit of iron ore in the form of a dike cutting sedimentaries is found on a small island in Mambulao Bay. It continues on the mainland

[4] Dalburg, F. A., and Pratt, Wallace E., *This Journal, Sec. A* (1914), 9, 201.

[5] See footnote 2.

[6] *This Journal, Sec. A* (1911), 6, 463.

where there are conspicuous outcrops. The strike is about north 5° west. This ore body has a width of as much as 13 meters at several places. Smaller outcrops occur near by. The ore is high grade hematite and is a workable deposit containing an immense tonnage.

Rinne, previously quoted, found that the blocks of ore at Bato-bolani were distributed over an area 200 meters (650 feet) wide by 400 meters (1,300 feet) long. He questioned the popular belief that the whole mountain was iron ore, however.

The area on Calambayanga Island over which blocks of iron ore are distributed is roughly 500 meters (1,650 feet) long and 200 meters (650 feet) wide, and blocks of the largest size are found all the way from sea level up to an elevation of 70 meters. There is every evidence that these great masses of ore have not been transported far; they must be practically in place. But from the nature of the ore deposit, it is obviously not safe to assume that beneath the surface there is a solid body of ore with dimensions equal to that of the area over which the surface blocks are scattered. The shape of the ore body may be very irregular, and without more data than is at present available no definite estimate of the quantity of ore can be made. If the ore deposit originated as suggested in this paper, the ore should persist with depth—that is, it should not be confined to the present surface. However, its vertical dimensions, like its horizontal dimensions, are probably irregular and cannot be estimated.

The ore on the island appears to be sufficient in quantity to be commercially important. It is probable that there is even a greater quantity of ore on the adjacent mainland, and the smaller island of ore to the west of a line from Calambayanga Island to the ore on the mainland is evidence of even wider ramifications of the mineralization. The ore in sight is undoubtedly to be estimated in hundreds of thousands of tons, but the total quantity of ore available is undetermined. It is impossible to escape the conviction, however, that the surface indications warrant capital in making the exploration requisite to determine the extent of the ore body. Preliminary exploration could probably be accomplished best by diamond drilling, and the expense of drilling at this site should be close to the minimum for this class of exploration.

ILLUSTRATIONS

TEXT FIGURES

FIG. 1. Map, showing situation of Calambayanga Island, Camarines Province.
2. Map, showing the location of the Calambayanga iron-ore deposits, Camarines Province.

IRON ORE IN SURIGAO PROVINCE [1]

By WALLACE E. PRATT and VICTOR E. LEDNICKY
(From the Division of Mines, Bureau of Science, Manila, P. I.)

ONE PLATE AND 1 TEXT FIGURE

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INTRODUCTION

Between the towns of Gigaquit and Cantilan on the eastern coast of Surigao Province, Mindanao, the country is conspicuously barren of vegetation, and the hills are covered with a mantle of red soil. The barrenness of these hills, so strongly in contrast with the heavy forests commonly observed in uninhabited country, has often attracted attention and comment. The Coast and Geodetic Survey charts of this coast, for instance, bear the notation "Red Hills" across the central part of the barren region.

Mr. H. F. Cameron, chief engineer for the Department of Mindanao and Sulu, first recognized the true character of the red earth which makes this section of the coast so conspicuous. Mr. Cameron was struck with the similarity between the Surigao red earth and the clayey iron ores of the Nipe Bay region in Cuba. He procured samples, which were analyzed by official request in the Bureau of Science, and were proved to be in reality high-grade iron ore. Mr. Cameron believed his samples to be representative and that the deposit of iron ore was enormously large. Following this report, which was made officially, the area covered by the ore was reserved by executive order from mineral location, pending a further examination to determine the character of the ore and the extent of the deposit. This paper contains the results of the official examination which was made during the latter part of February and the first part of March, 1915.

[1] Received for publication June 29, 1915.

GEOGRAPHY

SITUATION

The reservation which was made to cover the Surigao iron ores includes all territory lying east of a north-south line through the town of Gigaquit and north of an east-west line through the town of Cantilan. These lines, together with the sea coast, define a triangular area in the eastern part of northern Surigao. Gigaquit, the northern point of the reservation, is about three hours' journey by small coasting steamer southeast of Surigao,

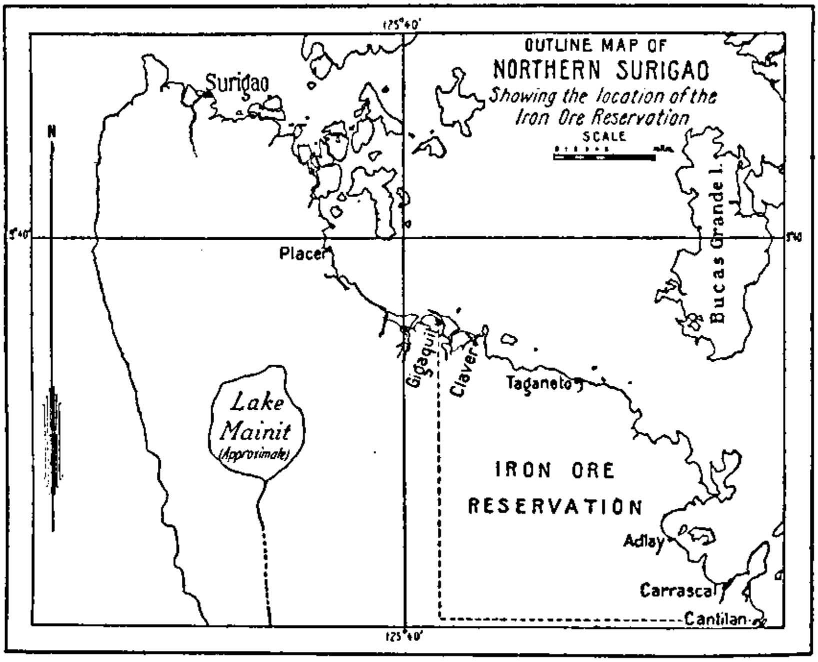

FIG. 1. Outline of northern Surigao, showing situation of iron-ore deposit.

the provincial capital and port of call for boats from Manila (see Plate I and fig. 1). The territory actually covered by the iron-ore formation is considerably smaller than the reservation, but occupies a strip along the coast within the boundary lines. The sea off the eastern coast of Mindanao is exceedingly rough during six months of the year, and good harbors are scarce. Practically the only natural harbor in the iron-ore region is Dahikan Bay. The waters inside this bay are thoroughly protected at all times and are abundantly deep (18 to 28 fathoms). However, the entrance to the bay is narrow and might be difficult of passage in rough weather.

PHYSIOGRAPHY

The iron-ore deposit covers a region which attains only moderate elevations, but is of sharp relief. Mount Legaspi, elevation 1,170 meters, is the highest point included within the boundaries of the iron-covered territory. Other peaks near the western edge of the deposit are as high as from 500 to 700 meters. The region slopes from Mount Legaspi eastward and northward to the coast, but the slope is by no means regular or continuous. The country is deeply incised; even the smaller streams flow through deep and precipitous valleys. This is a result of the exceedingly heavy rainfall between the months of October and March. The weather-recording station at the town of Surigao shows an average annual rainfall of over 3,000 millimeters, most of which occurs during the above-stated months. The hills rise abruptly from the coast, and much of the coast line is marked by sea cliffs. The outline of the coast is fairly regular, but is broken by several prominent points and bays.

Only two rivers of any size flow across the iron-ore deposits. One of them, flowing north, discharges its waters into the sea at the barrio of Taganito; the other drains the eastern flank of Mount Legaspi and flows to the south, reaching the sea at Carrascal. Either of these rivers could probably be made to yield a fair amount of water power, but no data are available on their volumes.

VEGETATION

One of the most remarkable features of the ore deposit is the unusual character of the vegetation covering it. Near the coast and over most of the area of the deposit the ground is largely bare, with scattered clumps of brush or shrubs and occasional patches of weedlike ferns. Everywhere, however, there is evidence of a former forest growth in the decaying trunks of fallen or even standing trees. These dead trees were as large on the average as those one finds growing in the normal forests at present. The trunks are almost invariably charred by fire, and charred resins are found very commonly over the ground surface. We suspect that the deposit was originally covered by a heavy forest which has been removed by fire within comparatively recent time. Toward the interior the vegetation gradually assumes the character of the surrounding forested region. In the western part of the deposit, where the forest is heavy, we thought at first that the ore was of lower grade. It had gradually changed in color from a deep red at the coast to a yellowish brown at the western limit of the deposit, the change correspond-

ing closely with the increase in vegetation. Analyses, however, proved the iron content to be just as high in the earth which supported the heavy forest as in the more highly colored mantle on the bare hills.

Specimens of a half dozen of the plants which are most abundant over the barren portions of the ore deposit were submitted to Mr. E. D. Merrill, botanist of the Bureau of Science, who stated that they belong without exception to the flora of high altitudes in the Philippines.[2] The best-known types had not previously been found below an elevation of from 500 to 600 meters and were commoner at elevations of 1,500 meters, whereas the specimens submitted were all secured at elevations ranging from sea level up to possibly 200 meters. Two of the specimens were evergreens belonging to the pine family, another was an edible blueberry which is common in the highlands of northern Luzon, while the commonest plant observed is the weedlike fern already mentioned. Pitcher plants, some of which produce pitchers of extraordinary size, abound in the region of the iron-ore deposit, but these, also, are found in other parts of Surigao.

GEOLOGY

The iron ores are clayey residual products from the surface decomposition of igneous rocks. They are similar to the laterites in origin found commonly in tropical countries. The parent rock in Surigao is subsiliceous in character and is probably a peridotite, but wherever exposed it is so completely altered as to make the determination of its original character difficult. The outcrops which are most widely distributed consist essentially of serpentine. On the beach, throughout the length of the deposit, rocks of other types are found locally and probably occur as dikes cutting the main rock mass. The dike rocks include diorites, gabbros, and felsitic to porphyritic andesites. Schist has also developed locally, probably in shear zones, and occurs in rare fragments along the beach.

Sedimentary rocks, principally tuff-sandstone and crystalline limestone, overlie the igneous basement, the alteration of which has given rise to the iron ore, and the line of contact between the basement rocks and the overlapping sedimentaries marks the limit of the ore deposit toward the interior. The sedimentaries outcrop on the coast at Capandan southeast of Claver

[2] Unfortunately Mr. Merrill's memorandum containing the classification of these plants was misplaced and because of his absence on leave cannot be replaced in time for publication in this paper.

Point, and the line of contact between them and the ore deposit runs south-southest. Blocks of limestone are found resting on the ore formation on the hill southwest of Capandan. Judging from the character of this limestone, the sedimentaries are probably of Miocene age. An escarpment marks the edge of the sedimentaries and forms a prominent line of hills trending south-southeast back of Capandan. The sedimentary rocks appear on the coast on the southern edge of the ore deposit in the ridge at Carrascal, the line dividing them from the ore deposit passing westward beyond Mount Legaspi. Thus the heavy, broken line which delimits the ore deposit in Plate I marks, also, the line of contact between sedimentary and igneous rocks throughout most of its course. The line approaches more closely to the summit of Mount Legaspi, however, than do the sedimentaries to the west, because the upper slopes of this peak show very little ore. It recurves, also, at its southern extremity to separate the area of alluvium around Carrascal Bay from the iron-ore formation. The numerous small islands which lie off the coast between Capandan and Carrascal are all composed of sedimentary rocks, except Ludguron Island in Carrascal Bay, which is partly covered with iron ore.

CHARACTER OF THE IRON ORE

The ore is principally ferruginous clay, but contains also an abundance of small, round pellets of hydrous iron oxides, as well as fragments or crusts of the parent rock, much altered, porous, and iron-stained, but maintaining their original form. Mineralogically the ore is probably a series of hydrous iron oxides related to limonite. The surface of the deposit is a deep reddish brown, almost crimson at places, but beneath the surface the color is lighter—a yellowish brown—while the transition stage between the ore and the underlying rock is pale green. The thickness of the mantle of ore varies irregularly up to a maximum of about 20 meters. The ore in place is soft and very spongy or mealy. In walking over it one often breaks through the crust into small openings or cavities beneath the surface.

The iron ores of the Nipe Bay region in Cuba appear to be similar in every respect to the iron ore in Surigao, and the reader who desires more detailed information will find elaborate descriptions of the Cuban ores with studies of the various steps in the alteration processes from serpentine to hydrous iron oxides.[3]

[3] The Mayari Iron-Ore Deposits, Cuba, by James F. Kemp, is especially good. *Bull. Trans. Am. Inst. Min. Eng.* (1915), 98, 129.

The chemical composition of the Surigao ore is shown in the following tables. Table I contains the analysis of a sample taken by Mr. Cameron and an analysis of similar ore from Mayari, Cuba, quoted from Kemp.[4]

TABLE I.—*Analysis of iron ore from Surigao Province.*[a]

Constituent.	Surigao ore.	Cuban ore.
	Per cent.	*Per cent.*
Hygroscopic water	13.50	----------
Combined water	6.60	11.15
Silica (SiO_2)	1.04	2.26
Alumina (Al_2O_3)	10.56	14.90
Ferric oxide (Fe_2O_3)	66.80	68.75
Ferrous oxide (FeO)	0.36	0.77
Chromium oxide (Cr_2O_3)	1.15	1.89
Sulphur	trace	----------
Phosphorus	trace	----------
Nickel oxide (NiO)	none	0.74
Total	100.01	100.46
Metallic iron, dry ore	54.29	48.65
Metallic iron, ignited ore	58.20	54.20

[a] Analysis by Francisco Peña, chemist, Bureau of Science.

Two other samples submitted by Mr. Cameron contained 51.92 and 54.15 per cent, respectively, of metallic iron in the dried ore.

The determinations appearing in Table II were made upon drill-hole samples taken by us. The figures show the percentage of metallic iron in the dried ore and in the sintered ore. The latter figure is employed for the purpose of making possible a direct comparison of the Surigao ore with the Cuban ore, which is sintered or nodulized before it is smelted. Sintering is a necessary preliminary to the smelting of clayey ores, and the column containing the figures for the iron content of the sintered ore also shows the proportion of iron which a smelter could expect in ore from Surigao. It is assumed that the Surigao ore will reabsorb about the same quantity of moisture after sintering that the Cuban ores do. Kemp[5] states that the nodulized or sintered Cuban ore contains from 3 to 3.5 per cent of water; therefore the column of percentage of iron in the sintered ore is based on the weight of the ignited ore plus 3.5 per cent for reabsorbed water.

[4] Op. cit., 147.

[5] Op. cit., 131.

TABLE II.—*Iron content of Surigao iron ore.*[a]

Drill hole. No.	Drill hole. Depth.	Description of sample.	Loss on ignition; ore dried at 110° C.	Metallic iron in dry ore.	Metallic iron in sintered ore.[b]
	Meters.		*Per cent.*	*Per cent.*	*Per cent.*
		Western edge of deposit south of Taganito: Surface ore	14.76	53.40	60.5
		Central portion of deposit inland from Hinadkaban Bay:			
		Depth—			
1	9	0-3 meters	12.50	47.30	52.2
		3-6 meters	12.70	42.56	47.0
		6-9 meters	12.20	29.59	32.5
		Southern portion of deposit; mainland near Dahikan Bay:			
		Depth—			
10	4	0-3 meters	12.20	31.00	33.0
12	12	0-3 meters	12.60	47.30	52.2
		3-6 meters	11.08	55.75	60.5
		6-9 meters	11.80	42.56	46.6
16	12	0-3 meters	13.34	49.81	55.7
		3-6 meters	13.49	50.89	56.8
		6-9 meters	12.02	54.36	59.7
		9-12 meters	12.13	51.96	57.2
20	8	0-3 meters	11.50	54.50	59.5
		3-6 meters	10.00	49.95	53.6
36	9	Surface	14.10	46.79	52.5
		Southern portion of deposit; peninsula near Dahikan Bay:			
		Depth—			
17	12	0-3 meters	13.05	45.64	50.7
		3-6 meters	11.04	37.16	40.4
		6-9 meters	10.57	48.01	51.9
		9-12 meters	11.93	54.86	60.2
29	3	0-3 meters	13.30	44.45	49.7
33	9	0-3 meters	14.25	48.30	54.4
		3-6 meters	14.45	49.10	55.4
		6-9 meters	13.15	51.40	57.3
		Northern part of ore deposit; inland from Taganito:			
		Depth—			
72	11	0-3 meters	14.16	45.64	51.4
		3-6 meters	12.41	45.63	50.3
		6-9 meters	13.60	42.28	47.3
76	6	0-3 meters	13.60	52.20	58.3
79	9	0-3 meters	15.34	47.39	54.0
		3-6 meters	14.00	48.16	54.0
		6-9 meters	13.57	51.39	57.5
85	6	3-6 meters	14.40	49.98	55.8
		Average	12.87	47.40	52.5

[a] Analyses by T. Dar Juan, A. S. Arguelles, and Francisco Peña, chemists, Bureau of Science.
[b] Calculated on a basis of 3.5 per cent reabsorbed moisture.

The material from each 3 meters of drill hole constitutes a separate sample. Occasional samples were taken from the surface, also. The analyses tabulated are on samples selected as representative of a total of 183 samples, taken from 89 different drill holes. The drill holes were located at regular intervals, usually at the corners of 300-meter squares, and groups of drill holes were distributed over different parts of the ore deposit.

From the foregoing analyses it appears that the average ore from Surigao would contain 52.5 per cent of iron after being sintered or nodulized in preparation for smelting. If two conspicuously poor samples, both of which probably are contaminated with the underlying parent rock, be excluded, the average iron content of the sintered ore becomes 53.9 per cent. Even this figure is somewhat lower than the average iron content of the ore mined at Mayari, Cuba, by the Spanish-American Iron Company. The yearly output of this company averages 48 to 49 per cent iron in the dry ore and 55 to 56 per cent iron in the nodulized ore.[6] Another important difference between the Cuban ore and the ore from Surigao Province is in their respective nickel contents. The average Cuban ore carries about 1 per cent of nickel, while no nickel has been detected in the Surigao ore.

The observation has been made in the Cuban deposits that the iron content of the ore increases for a certain distance below the surface and then declines. The samples from Surigao show a similar change generally, but not in all cases; some holes reveal a progressive decrease from the surface downward. It is notable that the very shallow holes encountered relatively poor ore, while the deepest holes show the best ore. This may be due in part, however, to a tendency to drive the shallow holes farther into the parent rock, proportionally, than in the cases of the deeper holes.

QUANTITY OF ORE

The quantity of ore is estimated upon a basis of the total area of the iron-ore deposit as determined by our reconnaissance surveys and the average depth of the ore as determined by drilling. The Coast and Geodetic Survey base map upon which our surveys are plotted is accurate, but the position of the line which marks the interior limit of the deposit is determined only approximately. The figure for the average depth of the ore is

[6] Kemp, James F., loc. cit., 131.

obtained by dividing the whole deposit into two classes—good areas and poor areas—the boundaries of which were determined by our observations in the field. This classification applies to the nature of the deposit, not to the character of the ore. The average depth of ore in each area is estimated from the results of groups of drill holes in that area. The various areas over which the ore is of good depth (indicated in Plate I) are again divided into two groups, one of which includes two areas which are accessible from Dahikan Bay and the other includes five areas which must be exploited from another base—probably from Taganito.

The total area of the ore deposit is about 100 square kilometers. This figure is less than the area of the deposit as outlined in Plate I by reason of the exclusion of several patches of alluvium and some of the steeper slopes which are not covered by ore. Probably 30 per cent of the deposit, exclusive of the good areas, is so inaccessible and so covered with forest that the ore upon it would have no commercial importance.

The areas classed as good aggregate 30 square kilometers. They include flat-lying portions of the deposit over which the ore is known to be of good depth. The two areas which are accessible from Dahikan Bay, the most feasible base of operations, contain 15 square kilometers.

Four groups of drill holes were located in the areas classed as good: One group of 56 holes placed regularly (some 150 meters, some 300 meters, and some 500 meters apart) in the vicinity of Dahikan Bay; one group of 2 holes in the vicinity of Hinadkaban Bay; and one group of 23 holes, 300 meters apart, in the vicinity of Taganito. One group of 17 holes, spaced at 150-meter intervals, was located in a poor area near Dahikan Bay. It may be objected with some reason that the number of holes and the area over which they are distributed are both limited and are hardly a sufficient basis for judging the whole ore deposit. The result which we obtained, however, both on the chemical character and the thickness of the ore, from widely separated groups of holes, are uniform enough to make us confident of the approximate correctness of our results considered as preliminary estimates. At any rate, the reader, knowing the basis upon which the estimates are made, will draw his own conclusions as to their accuracy.

Of the drill holes located in good areas, 6.8 per cent fell on bare rock, thus encountering no ore; 28.8 per cent encountered from 0.5 to 3 meters of ore; 34.3 per cent encountered from

3 to 6 meters of ore; 21.9 per cent encountered from 6 to 9 meters of ore; 6.8 per cent encountered from 9 to 12 meters of ore; and 1.4 per cent encountered from 12 to 15 meters of ore. The analyses indicate that a few of the holes did not penetrate to the underlying parent rock. On the other hand, some of them went into the parent rock farther than mining operations would extend. Hence, these two possible sources of error in the determination of the average depth tend to balance each other. The holes were always continued until they struck hard rock, and usually represent the actual thickness of the surrounding ore.

Of the drill holes located in poor areas, 29.4 per cent encountered no ore; 58.8 per cent encountered from 0.5 to 3 meters of ore; 5.9 per cent encountered from 3 to 6 meters of ore; and 5.9 per cent encountered from 6 to 9 meters of ore.

Specific gravity determinations on small pieces of the ore indicate that its dry weight in place must be from 1.7 to 2.5 metric tons per cubic meter. This estimated unit weight may appear to be low for an iron ore, but as a matter of fact the Surigao ore is very porous. In the following estimates it will be assumed that 1 cubic meter of dry ore weighs 2 metric tons.

According to these figures the areas of good ore contain 275,400,000 metric tons of ore as follows:

TABLE III.—*Quantity of ore in good areas.*

Average depth (meters).	Quantity.	
	Cubic meters.	Metric tons.
1.75	15,100,000	30,200,000
4.50	46,300,000	92,600,000
7.50	49,200,000	98,400,000
10.50	21,400,000	42,800,000
13.50	5,700,000	11,400,000
Total	137,700,000	275,400,000

If it be assumed that only areas over which the average depth is 3 meters or more can be exploited economically, the total available tonnage becomes 260,300,000. One half of this quantity, or 130,150,000, is fairly accessible from Dahikan Bay as a base.

The quantity of ore included in the area classed as poor is 222,400,000 tons, as follows:

TABLE IV.—*Quantity of ore in poor area.*

Average depth (meters).	Quantity.	
	Cubic meters.	Metric tons.
1.5	61,800,000	123,600,000
4.5	18,500,000	37,000,000
7.5	30,900,000	61,800,000
Total	111,200,000	222,400,000

If it be assumed that only areas over which the average depth is 3 meters or more will prove valuable, the available tonnage in the poor area becomes 160,600,000. Again, if our belief that 30 per cent of the poor area is too remote and too heavily forested to repay exploitation is correct, the total available tonnage over the poor area is 155,680,000, of which 112,420,000 tons form a layer of 3 meters or more in thickness.

In summary, the total iron-ore reserves in the Surigao deposit amount to approximately 500,000,000 metric tons. Of this total quantity about 430,000,000 tons are fairly accessible for mining, although by no means conveniently situated, and 373,000,000 tons are contained in that portion of the ore mantle which is 3 meters or more in thickness. On the flat-topped barren hills which border the coast there are 275,000,000 tons of ore. This ore is comparatively accessible, but is divided into a number of separate areas. That portion of it which is 3 meters or more in thickness amounts to 260,000,000 tons. Finally, from Dahikan Bay, which offers natural harbor facilities, two blocks of ore could be exploited containing an aggregate tonnage of 138,000,000, with 130,000,000 tons forming a deposit 3 meters or more in thickness. However, even from this most favorable base the bulk of the ore must be brought down to sea level from the tops of hills, ranging in elevation from 200 to 400 meters.

COMMERCIAL POSSIBILITIES OF THE DEPOSIT

The Surigao iron ores constitute a natural resource which will probably be more valuable in the future than it is to-day. At present the demand for iron and steel in the Philippines is not sufficient to justify the large-scale operations which would be necessary for the proper exploitation of the Surigao deposits. An ore which is richer in iron is available at Mambulao, Camarines, in adequate quantity and under conditions just as favorable as the conditions which obtain in Surigao. Yet no success

has attended the efforts so far made to exploit the Camarines ore. The Surigao ore possesses an advantage in its freedom from objectionable impurities, such as sulphur and phosphorus, although neither of these elements is injuriously high in the Camarines ore.

The best authorities believe that the Cuban ore, with which the Surigao ore has been compared, will ultimately be exported to Europe as well as to the United States. But one of the features which make the Cuban ore valuable is its nickel content. This metal, so desirable in certain classes of steel alloys, is not present in the Surigao ore. Then, too, the Surigao ore is poorer in iron than the Cuban ore, and while the difference in the iron content is small, it is sufficient to make a difference in the smelting values of the two ores.

If the Surigao deposit is exploited in the near future it will probably be for the purpose of exporting the ore to be smelted elsewhere. The present export tax of 2 pesos per metric ton on ores would make difficult the profitable mining of the ore, even for export. The lack of coke for reduction, as well as the limited market for the product, militate against the development of a local iron- and steel-smelting industry. On the other hand, when in time the Philippine market becomes large enough to justify manufacturing iron and steel from these ores, the problem can probably be solved by utilizing one of the larger streams for hydroelectric power and accomplishing the reduction in the electric furnace with charcoal burned in the surrounding forests.

Dahikan Bay, which is protected from the rough seas common to the eastern coast of Mindanao throughout one half the year, offers the best situation for a base of mining operations. Not only does it afford the only natural harbor facilities in the region, but it is adjacent to the largest area of ore. Power will have to be transmitted from a distance, but this is true, also, of any other possible location. Taganito is another possible base of operations. It has no natural harbor facilities, although there are outlying islands which might prove of value in making a harbor. But it is the logical point from which to mine a large quantity of ore, as it affords a larger area for the plant site than is available at Dahikan Bay and has more water for general purposes, and water for power could be obtained on the upper parts of several rivers which discharge at Taganito.

Wherever mining is attempted in the Surigao deposit, it will be necessary to mine the greater part of the ore on the tops of the hills varying from 150 to 400 meters in elevation and to transport the mined ore down steep slopes to sea level.

ILLUSTRATIONS

PLATE I. Topographic map of iron-ore deposit in Surigao, showing (red cross-hatched areas) best parts of deposit.

TEXT FIGURE

FIG. 1. Outline map of northern Surigao, showing situation of iron-ore deposit.

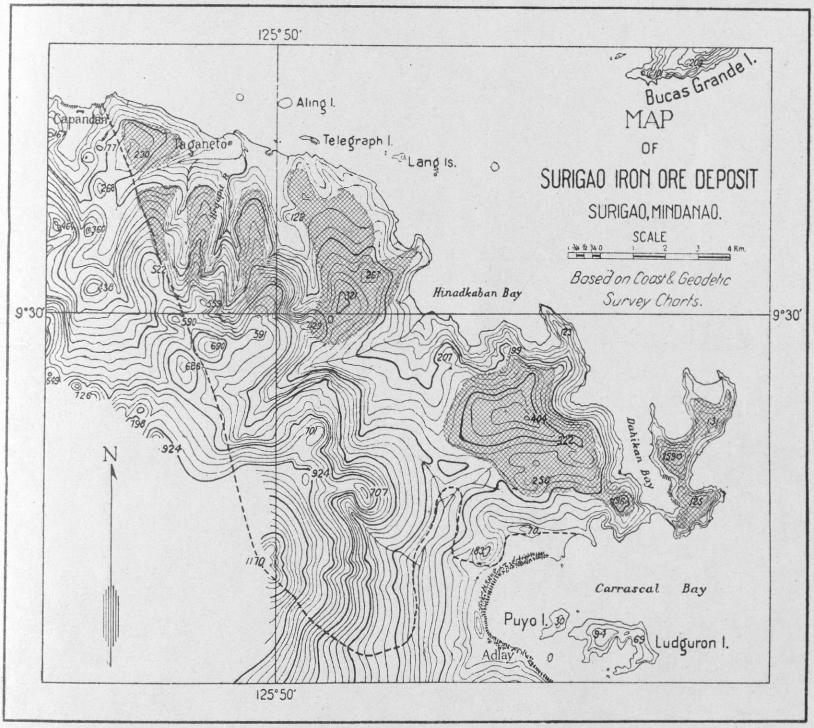

PLATE I. TOPOGRAPHIC MAP OF IRON-ORE DEPOSIT IN SURIGAO, SHOWING (RED CROSS-HATCHED AREAS) BEST PARTS OF DEPOSIT.

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